Verification of Hydrodynamic Calculations
Rev 2

A Report for

Alan Kenney
Associated Power Ltd
Wrexham, LL1 5EH

Project No: APO005 **Report No: 2018/701** **Date: April 2019**

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Alan Kenney
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Wrexham, LL1 5EH

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Revision History

Date	Revision	Description	Prepared by
Dec 2018	1	First version	Sandy Black
Apr 2019	2	Minor corrections	Sandy Black

Date: April 2019

SUMMARY

Associated Power Ltd have proposed an Energy Conversion System (ECS) and have provided TUV SUD NEL with calculations of the system within a document entitled “The Energy Conversion System (ECS) Basic Principles of Operation. Design of a 30 kW ECS Unit”. Associated Power Ltd have built a small test rig in Wrexham with some instrumentation to demonstrate the principles of the basic ECS operation, but it is not equipped to produce power due to its small scale.

The system consists of a pressurised manifold tank which moves dense media to a turbine through a magnet separator. The water from the turbine is displaced upwards to back-up tanks where it is also mixed with the dense media that has been pumped from the manifold tank. The mixture is then returned back to the manifold tank where the process is repeated. The ECS is designed to operate continuously out of balance with a g-force continually displacing water upwards as it attempts to rebalance the system. The ECS system generates electrical output from the turbine and consumes power from the pump, magnet separator and other auxiliaries.

The study undertaken by NEL was aimed at assessing the calculations given key input information from Associated Power Ltd. This involved considerable discussion and an understanding of the complexities of the system alongside the experimental experience from Associated Power Ltd.

The current verification is based on established hydrodynamic models from the literature which are predominantly valid under steady state conditions, however the system is inherently transient in nature and would benefit from unsteady calculations. In particular, the effect of system losses in key areas such as the rising and falling of the water in the BU tanks alongside the ‘back-up phenomena’ witnessed during experimental testing on a small scale rig would be advantageous to understand mathematically.

Preliminary evidence suggests that if the system can physically work, the system could generate a net power providing all assumptions can be physically verified. Overall, it is of the opinion of NEL that there is insufficient evidence to fully verify the ECS theoretically. To summarise, the components which can and cannot be verified are highlighted below:

The hydrodynamic calculations of the components which can be verified include the selection of the pump and suitable base pressure to move the dense media from the manifold tank through the system up to the back-up tanks at a height of 35 m. During small scale testing by Associated Power, a ‘back-up’ phenomena was observed where media would mix in the back-up tanks and allow the media back into the manifold tank. This could not be verified with existing models and this phenomenon would benefit from a pilot scale experiment with pressure measurements and CFD analysis to derive a suitable verified model.

The base pressure is sufficient to move the media through a magnet and turbine to the back-up tanks; however, this assumes minimal loss of head pressure through the magnet. A zero head loss is assumed for the magnet, however this may also act as a crude pump as it rotates, however, further experimental data is required to build a suitable model at the scale and efficiency required for this system.

Overall, the ECS requires additional experimentation and modelling to ensure the system can work continuously. As the system is inherently transient, unsteady simulations such as CFD or process modelling can be used. It is recommended that calculations are first verified by experiments on a pilot scale facility that will produce power and provide significant valuable data to aid the development of bespoke models suitable for this system and deploy this technology at a larger scale.

TABLE OF CONTENTS

1 INTRODUCTION

Associated Power Ltd have proposed an Energy Conversion System (ECS) and have provided TUV SUD NEL with calculations of the system within a document entitled "The Energy Conversion System (ECS) Basic Principles of Operation. Design of a 30 kW ECS Unit" [**1**]. This document will be referred to as the ECS document throughout this report.

The Energy Conversion System applies a force to move a mass of water to a height giving potential energy which when allowed to fall from height gives kinetic energy. The ECS is designed to operate continuously out of balance with a g-force continually displacing water upwards as it attempts to rebalance the system. A schematic of the ECS is shown in Figure 1

Associated Power Ltd have built a small test rig in Wrexham with some instrumentation to demonstrate the principles of the basic ECS operation, but it is not equipped to produce power due to its small scale [1].

2 SCOPE OF WORK

This report covers a check of the hydrodynamic calculations provided to TUV SUD NEL by Associated Power Ltd as outlined in the quotation reference NEL-15148 [2].

3 METHOD AND APPROACH

Associated Power Ltd provided a documentation to NEL with the calculations and assumptions. Each of these is classified into different sub-sections. The report examines each of those points.

4 CALCULATION ASSESSMENT

Within the ECS document, the calculations and assumptions are presented and are included in the appendix. A series of email communication between NEL and Associated Power Ltd was also conducted where the design was modified from the original proposed in the ECS document. This document includes the latest design as determined by Associated Power Ltd.

The current verification is based on established hydrodynamic models from literature which are predominantly valid under steady state conditions. However, the system is inherently transient in nature and would benefit from unsteady calculations.

For the purposes of verifying the calculations, the values computed by NEL were compared against those calculations by Associated Power Ltd.

4.1 Overview

The ECS document describes the overall operation of the system. Three liquid compositions are circulated, mixed and separated in a continuous process that are namely dense media at 3 sg, water at 1 sg and a mixture around 2.33 sg.

As shown in Figure 1 the dense media at 3 sg is driven by a centrifugal pump in Column 1 from an air locked manifold tank to a height of approximately 35 m whereby it is mixed with two spherical back-up tanks of water. These tanks operate continuously out of balance (i.e. one is drained whilst the other is filled). The mixed media then moves down Column 2 to the manifold tank. The media is also fed to a magnetic separator that separates the mixed media into very dense media (~5.7 sg) and water. A branch is also present to fluidise the dense media, if required. The very dense media is passed back into the manifold tank while the water is passed through a water turbine which extracts energy from the flow and the remaining water flows back up to the back-up tanks.

The system is designed to operate continuously. The design is based on a base pressure (i.e. the hydrostatic pressure of the liquid at the bottom of the system) and is only open to atmosphere at the back-up tanks, therefore the media is each component constitutes to the computation of the base pressure. The design is analogous to filling and draining a tank problems (i.e. the pressures are known based on the media composition and the height of the system and is referred to as the 'bottom-up' approach).

4.2 Dense media calculation

Within the ECS document, the assumption relies on mixtures of dense media and water. The physical properties showing the density and viscosity of the ferro silicon required to make a dense media slurry is shown in Figure 2 and Figure 3, respectively.

Calculations by NEL regarding the fluid mixtures and properties are shown in Figure 4.

Associated Power Ltd have correctly calculated that (720 m^3/h) 200 l/s of media at 3 sg and (360 m^3/h) 100 l/s of water at 1 sg are required to create a mixture of 2.33 sg that is required for the downstream section in Column 2 of Figure 1.

As shown in Figure 4, the volume of FeSi (also named Ferro) is 22.60 % for 2.33 sg slurry. This is different to the 29.41 % which is reported in Appendix 6 of the ECS document.

4.3 System losses

An overview of the system components is shown in Figure 1 and is described in Table 1. The detailed calculation relating to these components is shown in Figure 5 and is described below. Frictional losses have been calculated by the Darcy Weisbach method with a specific roughness of 45 µm to represent a steel pipe.

The base pressure (P_{base}) is fixed at 106.1 mWg (1040 kPa) which is based on the media in the system. This is based on an average media of 3 sg in the system at height of 35 m plus 1.1 m of water. Components 1, 5, 6 and 8 either remove and introduce different density media into the manifold tank. Therefore, an alternative way to calculate the base pressure would be to include the water tank level (which changes with time), the downward column (5), the return from the magnet (8) and the level in the manifold tank. An exact calculation of the base pressure would be subject to testing or time-dependent analysis. Assuming steady state analysis, the above approximation is an adequate approximation of the base pressure.

The following analysis mainly refers to the two locations in each of the numbered components in Figure 5. The location at h0 and pressure at P0 refer to the start of the component or pipework whereas h1 and P1 refer to the height and pressure at those component or pipework.

Component 1 consists of a 3 m length pipe connecting the manifold tank to a Warman 400L pump at a height of 4 m above the manifold tank. The inlet of the pump is horizontal and the outlet is vertical, therefore it is assumed with 2 x 45° bend pipes are also included. The pipe has an internal diameter of 450 mm and has a flow of 720 m^3/h as governed by the pump (component 2). The pump is assumed to generate a suction of 270 mmWG based upon previous test experience (A. Kenney, Personal Communication, 20th November 2018). The velocity within the pipe is 1.26 m/s with a media of 3 sg. Accounting for the static and frictional losses, the pressure at the Warman 400L pump is 94.29 mWG.

Component 2 is the Warman 400L pump which has a 450 mm entry and a 400 mm exit. The pump is assumed to generate a head of 1 mWG. Velocity head is assumed to be accounted for in the manufacturer's specification and so the increase from 1.26 m/s to 1.59 m/s is assumed to be included in the generated head of 1 mWG. The system pressure at the exit of the Warman 400L pump is 95.29 mWG.

Component 3 consists of a vertically orientated 400 mm I.D. pipe which is 30 m in length. For a flow of 720 m^3/h with 3 sg fluid, due to the elevation of the fluid and frictional losses, the system pressure at this point is 5.07 mWG.

Component 4 consists of a 400 mm pipe with two 90° long radius 5 diameter pipe bends (1.57 m in length) with a tee junction connecting the back-up (BU) tanks. A head loss constant of 0.6 was assumed for the pipe bends and tee junction. After the first bend and the tee, the pressure is 1.90 mWG at the top of the system where the back-up tanks are positioned. The BU tanks are open to atmosphere and are filled with water. Based on water (1 sg), the media will flow out of the tanks if the level is above 1.9 m and media will flow into the tanks if it is below 1.9 m. Mixing of the water and media is likely to occur, however the exact position is difficult to determine. Experimental experience by Associated Power show that media does not mix with the water in the BU tank and drains (A. Kenney, Personal Communication, 23rd November 2018). The backup tanks are initially filled to the halfway mark at the start of operations which allows room for the active tank to rise, as water is drawn from the opposite tank.

Component 5 consists of a 400 mm pipe that is assumed to terminate 1.6 m from the base which is located inside the manifold tank. The BU tanks are designed to supply 360 m^3/h of water into the 3 sg mixture which would give a 2.33 sg mixture in component 5. Accounting for frictional losses and the additional head from the height of the system, a pressure of 80.9 mWG is calculated for the exit of Component 5. It is important to note, this is solely based on the height and frictional losses of the system. Due to the air-lock, component 5 is effectively part of the manifold tank as it contributes towards the system base pressure. At 1.6 m from the base, it is unlikely the media will flow freely into the tank under these assumptions, but rather the transient and cyclic nature of the system due to the filling and emptying of this tank may constitute to the media flowing into the tank. An experimental test facility which did not include the magnet or turbine has been observed by Associated Power at a smaller scale (A. Kenney, Personal Communication, 23rd November 2018). This facility should be used alongside a large facility to understand and develop mathematical models.

Component 6 consists of a 350 mm pipe which is 2 m in length and has 1 x 45° bend. The pipe leaves the manifold tank at approximately the same position as Component 5 and is assumed to have the same mixture of 2.33 sg. The magnet and turbine are positioned at 3.6 m above the base pressure line. The feed to the magnet is located approximately 2.5 m from the base of the system which is assumed to have a pressure of 98.6 mWG (106.1 mWG - 2.5 m height x 3 sg). At the entry to the magnet, the pressure is 95.96 mWG.

A media of 2.33 sg at a flow rate of 576 m3/h would result in a pressure of 95.96 mWG at the entrance of the magnet. Assuming, there is no loss over the magnet, the flow would leave the magnet via a 200 mm pipe with a length of 2 m reducing to 125 mm at the turbine inlet at a height of 3.6 m. A tee to bypass water is also included in the friction loss calculations as well as a regulating valve that is assumed to be fully open and contribute to zero losses. A turbine loss of 60 mWG equates to a 32.46 mWG pressure at the exit of the turbine. Component 9 delivers the water to the back-up tanks via a 32 m length of pipe with 2 x 45° bends at a flow of 360 m^3/h. At the back-up tanks, the pressure is 0.64 mWG, however this will also have to overcome the tank water level. Based on this analysis that would be 0.64 mWG.

The previous paragraph relies on an efficient magnet and to balance the system by mass, the magnet must produce a media with a density 4555 kg/m^3 at a flow rate of 216 m^3/hr back to the manifold tank via Component 8. This consists of a 250 mm pipe and at a height of 2 m would have a pressure of 112.32 mWG allowing the media theoretically back into the manifold tank. From a practical perspective, if the media does not flow back into the tank, this could be diluted by an additional line from the manifold tank as shown in the return line (8) in Figure 1.

The drum would rotate at approximately 60 rpm in the direction of the flow and may aid the flow into the magnet. As this cannot be quantified within the current calculations, a conservative approximation of zero head loss is assumed.

The most important criteria in these calculations is the appropriate calculation of base pressure. Different mixtures of water and media exist within the system which are removed and introduced at different rates. Due to the complexity of the system, a pilot scale test facility should be constructed to adequately examine the overall system and verify physical models.

4.4 Power requirements

The power input and output calculated by Associated Power Ltd is shown in Figure 7 and the calculation by NEL is shown in Figure 8. The two calculations agree based upon the specific assumption outlined in the system losses calculation in Section 4.3.

Pump curves for the Warman Centrifugal Slurry pump 400L were supplied to NEL as shown in Figure 9. The pump supplies an additional 1 m head for a 3 sg media and requires a power of 7.1 kW. Sufficient base pressure is exerted to allow for a pump with a lower head requirement. Within this study, the effect of mixing between the BU tanks at the tee junction and the back-up phenomena has been neglected as more detailed analysis is required. It is expected these processes to cause the power requirement or flow to fluctuate for a given upstream pressure as the BU tanks lose water and switch between tanks.

The turbine requires a head of 60 m which is delivered after the magnet producing a power output of 44.87 kW. The ECS document stipulates magnet and auxiliary losses of 4 kW, however this is based on a media of 2.33 sg for the magnet, therefore additional power may be required due to the changes in design.

Overall, if the system can physically work, the system could generate a net power. This considers:

Overall energy output 31.8 kW = Turbine (44.87 kW)
– Pump (7.10 kW)
– Magnet (4 kW)
– Auxiliaries (2 kW)

4.5 Further work

- More accurate pressure loss calculations from the mixing at the BU tanks using CFD or other analysis for the different density fluids. In particular, it is important to understand the root cause of this 'back-up' phenomena observed by Associated Power Ltd.
- Dynamic model undertaken by an appropriate process modelling software. This should help calculate the filling and emptying of tank as well as pump and turbine process

fluctuations. It would be useful to replicate and validate the models with Associated Power Ltd test facility to ensure the correct physics and pressure losses are captured.

- Construction of a pilot scale test facility to allow physical models to be benchmarked and design a full scale facility.

Utilising these tools will help refine the design of the ECS.

5 CONCLUSIONS

Associated Power Ltd have proposed an Energy Conversion System (ECS) and have provided TUV SUD NEL with calculations of the system within a document entitled “The Energy Conversion System (ECS) Basic Principles of Operation. Design of a 30 kW ECS Unit”. Associated Power Ltd have built a small test rig in Wrexham with some instrumentation to demonstrate the principles of the basic ECS operation, but it is not equipped to produce power due to its small scale.

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The hydrodynamic calculations of the components which can be verified include the selection of the pump and suitable base pressure to move the dense media from the manifold tank through the system up to the back-up tanks at a height of 35 m. During small scale testing by Associated Power, a ‘back-up’ phenomena was observed where media would mix in the back-up tanks and allow the media back into the manifold tank. This could not be verified with existing models and this phenomenon would benefit from a pilot scale experiment with pressure measurements and CFD analysis to derive a suitable verified model.

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6 REFERENCES

[1] The Energy Conversion System (ECS) Basic Principles of Operation. Design of a 30 kW ECS unit. *Associated Power Ltd. 2018*
[2] NEL Offer letter, NEL-15148, 2018

TABLES

Component	Description
1	450 mm I.D. pipe, 3 m length with 2 x 45° bend, exit flow: 720 m^3/h, 3 sg
2	Warman 400L pump, 450 mm entry, 400 mm exit, exit flow: 720 m^3/h, 3 sg
3	400 mm I.D. pipe, 30 m length exit flow: 720 m^3/h, 3 sg
4	400 mm I.D. pipe with 2 x 90° LR bends (5D). Straight pipe with 2 x 400 mm tees connecting BU tanks
5	400 mm I.D. pipe, 34 m length with 2 x 60° bends terminating 1.6 m from base, exit flow 1080 m^3/h, 2.33 sg
6	350 mm I.D. pipe, 2 m length with 1 x 45° bends, exit flow: 576 m^3/h, 2.33 sg
7	200 mm I.D. pipe, 2 m length reducing to 125 mm for turbine inlet with 1 x Tee to bypass water, 1 x regulating valve. Exit flow: 360 m^3/h, 1 sg
8	250 mm I.D. pipe, 3.6 m, exit flow: 216 m^3/h, 4.6 sg
9	250 mm I.D. pipe, 32 m length with 2 x 45° bend, exit flow: 360 m^3/h, 1 sg

Table 1 Description of system components

FIGURES

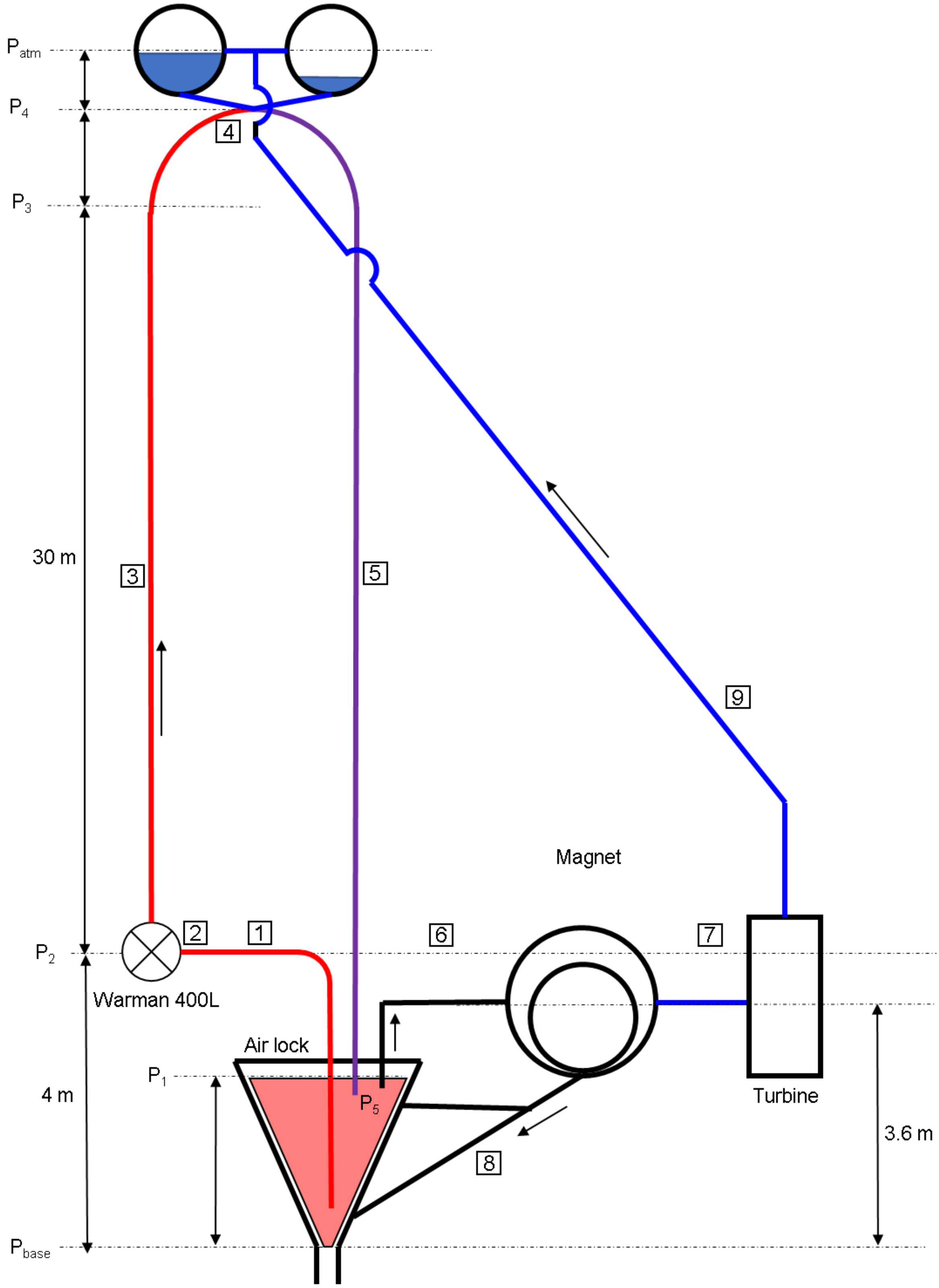

Figure 1 Overview and schematic of the ECS.

APPENDIX 2A

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WESTBROOK ATOMISED FERRO SILICON 15% DENSE MEDIA POWDERS

Material	:	**Atomised Ferro Silicon 15% - Cyclone 60 Grade**
Specification	:	Fe >80%, Si 14-16%, Mn <0.80%, Cr <0.60%, Cu <0.50%, P <0.10%, S <0.05%
Size	:	-212 Micron 100%, -150 Micron 99-100%, -106 Micron 96-100%, -75 Micron 82-94%, -45 Micron 68-78%, -20 Micron 32-42%
Apparent Density	:	3.3-4.1g/cc
Pycnometric Density	:	6.7-7.1g/cc
Non Magnetics	:	0.5% Max
Magnetic susceptibility	:	58% Min

Material	:	**Atomised Ferro Silicon 15% - Fine Grade**
Specification	:	Fe >80%, Si 14-16%, Mn <0.80%, Cr <0.60%, Cu <0.50%, P <0.10%, S <0.05%
Size	:	-212 Micron 97-100%, -150 Micron 90-96%, -106 Micron 74-88%, -75 Micron 60-75%, -45 Micron 42-50%, -20 Micron 15-25%
Apparent Density	:	3.7-4.1g/cc
Pycnometric Density	:	6.7-7.1g/cc
Non Magnetics	:	0.5% Max
Magnetic susceptibility	:	58% Min

Material	:	**Atomised Ferro Silicon 15% Coarse Grade**
Specification	:	Fe >80%, Si 14-16%, Mn <0.80%, Cr <0.60%, Cu <0.50%, P <0.10%, S <0.05%
Size	:	-212 Micron 96-98%, -150 Micron 87-93%, -106 Micron 72-82%, -75 Micron 51-67%, -45 Micron 32-42%
Apparent Density	:	3.7-4.1g/cc
Pycnometric Density	:	6.7-7.1g/cc
Non Magnetics	:	0.5% Max
Magnetic susceptibility	:	58% Min

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Figure 2 Ferro Silicon media properties from Appendix 2 of ECS document.

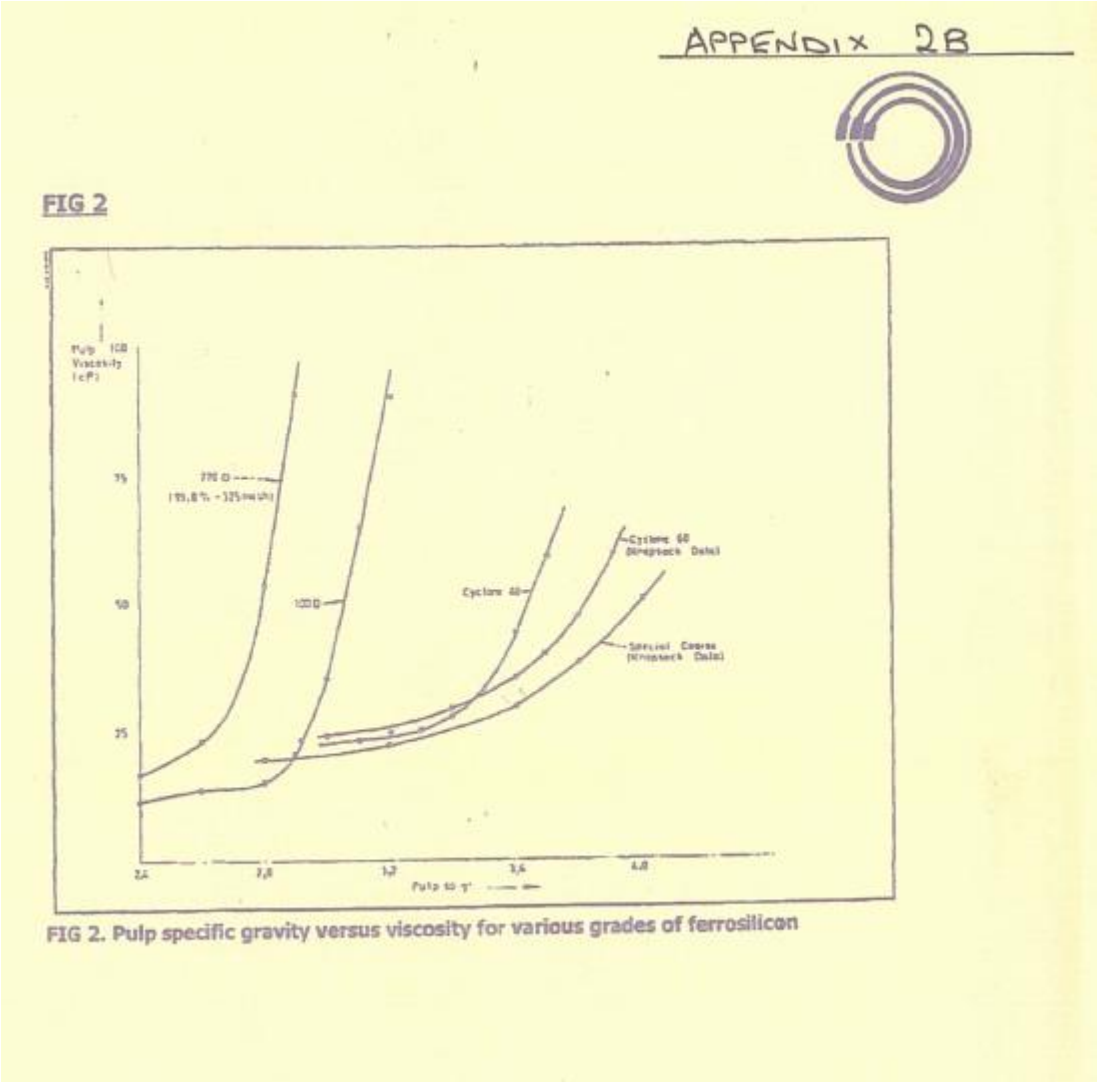

Figure 3 Ferro Silicon media viscosity curve from Appendix 2 of ECS document.

A. Fluid Properties and mixtures

Name	Density		Dyn visc.	Kin visc.	Reference
	sg	kg/m3	cP	cSt	
Water	1.00	1000	1.00	1.00	Note 1
Ferro Silicon	6.90	6900			Note 2,3

	Density		Water	Ferro	Water	Ferro	Water	Ferro	Reference
	sg	kg/m3	wt%	wt%	m3/kg	m3/kg	vol%	vol%	
3g slurry	3.00	3000	22.03	77.97	0.02	0.01	66.10	33.90	Note 4
2.33sg slurry	2.33	2333.33	33.17	66.83	0.03	0.01	77.40	22.60	Note 4

			Input				**Output**		Reference
			3 sg slurry	+	Water	=	2.33 sg slurry		
Creation of 2.33 sg slurry:	Flow	m3/h	720.00		360.00		1080.00		
	Volume	%	66.67		33.33		100.00		
	Density	sg	3.00		1.00		2.33		
		kg/m3	3000		1000		2333.3333		Note 5
	Dyn Viscosity	cP	25.00		1.00		17.00		Note 6
	Kin Visc	cSt	8.33		1.00		7.29		

References

Note 1	Standard density and viscosity of water at 20°C
Note 2	Average of 6.7 and 7.1 g/cc from Atomised Ferro Silicon 15% Cyclone 60 Grade, (Appendix 2A)
Note 3	Viscosity of 25 cP from Fig 2 in Appendix 2B of cyclone 60 material
Note 4	http://www.filtration-and-separation.com/concentration.asp
Note 5	Volumetric mixing rule
Note 6	Volumetric mixing rule but extrapolation using Fig 2 in Appendix 2B appears reasonable (other rules could be used e.g. Grunberg-Nissan mixing rule)

Figure 4 NEL slurry mixture calculations. Blue are inputs and yellow are outputs.

Input											
Calculation											
		[1]	**[2]**	**[3]**	**[4]**	**[4]**	**[5]**	**[6]**	**[7]**	**[9]**	**[8]**
Reference		Tank to Pump	Pump	Vertical upwards pipe	Pipe bend 1 + tee	Pipe bend 2 + BU water	Donwards vertical pipe	To magnet	Turbine	To BU tanks	Return from magnet
Input											
Height (h0)	m	0	4	4	34	35	34	2.5	3.6	3.6	3.6
Height (h1)	m	4	4	34	35	34	1.6	3.6	3.6	35	0
Pressure, guage (P0)	mwG	106.1	94.29	95.29	5.07	1.90	4.68	98.6	95.96	32.46	95.96
	Pa	1040456.9	924647.2	934451.3	49701.8	18656.1	45911.3	966909.1	941027.7	318301.8	941027.7
	kPa	1040.5	924.6	934.5	49.7	18.7	45.9	966.9	941.0	318.3	941.0
Pressure, guage (P1)	mwG	94.29	95.29	5.07	1.90	4.68	79.65	95.96	32.46	0.64	112.32
	Pa	924647.2	934451.3	49701.8	18656.1	45911.3	781089.6	941027.7	318301.8	6283.9	1101495.6
	kPa	924.6	934.5	49.7	18.7	45.9	781.1	941.0	318.3	6.3	1101.5
Density (rho0)	kg/m3	3000	3000	3000	3000	2333	2333	2333	1000	1000	4555
Density (rho1)	kg/m3	3000	3000	3000	3000	2333	2333	2333	1000	1000	4555
Pipe Inside Diameter (D0)	mm	450	400	400	400	400	400	350	200	250	250
	m	0.45	0.4	0.4	0.4	0.4	0.4	0.35	0.2	0.25	0.25
Pipe Inside Diameter (D1)	mm	450	400	400	400	400	400	350	125	250	250
	m	0.45	0.4	0.4	0.4	0.4	0.4	0.35	0.125	0.25	0.25
Flow Rate (Q0)	m3/hr	720	720	720	720	1080	1080	576	360	360	216
	m3/s	0.20	0.20	0.20	0.20	0.30	0.30	0.16	0.10	0.10	0.06
Flow Rate (Q1)	m3/hr	720	720	720	720	1080	1080	576	360	360	216
	m3/s	0.20	0.20	0.20	0.20	0.30	0.30	0.16	0.10	0.10	0.06
Average Velocity (v0)	m/s	1.26	1.59	1.59	1.59	2.39	2.39	1.66	3.18	2.04	1.22
Average Velocity (v1)	m/s	1.26	1.59	1.59	1.59	2.39	2.39	1.66	8.15	2.04	1.22
Average Dynamic viscosity	cP	25.00	25.00	25.00	25.00	17.00	17.00	17.00	1.00	1.00	250.00
Kinematic Viscosity (v)	cSt	8.33	8.33	8.33	8.33	7.29	7.29	7.29	1.00	1.00	54.88
	m2/s	8.333E-06	8.333E-06	8.333E-06	8.333E-06	7.287E-06	7.287E-06	7.287E-06	1.000E-06	1.000E-06	5.488E-05
Specific Roughness (Є)	m	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05	4.50E-05
Pipe Length (L)	m	3	0	30	1.57	1.57	32.4	2	2	31.40	3.6
Component gain (+ve) / loss (-ve)	m	0.27	1	0	0	0.64	0.00	0.00	-60.00	0.00	0.00
Pressure, abs (P1)	Pa	1025972	1035776	151027	119981	147236	882415	1042353	419627	107609	1202821

Figure 5 Calculated system losses. Blue is input values, yellow is calculated. Red cells highlight important considerations or warnings in the design calculation, and green cells highlight calculated values that are considered sensible. The pressure, absolute values are shown to check the system does not go below vapour pressure (assumed here to be that of water at 20°C).

		[1]	[2]	[3]	[4]	[4]	[5]	[6]	[7]	[9]	[8]
		Tank to Pump	Pump	Vertical upwards pipe	Pipe bend 1 + tee	Pipe bend 2 + BU water	Donwards vertical pipe	To magnet	Turbine	To BU tanks	Return from magnet
Calculated Data											
Reynolds Number		67906	76394	76394	76394	131050	131050	79878	636620	509296	5568
Darcy Friction Factor		0.020	0.019	0.019	0.019	0.018	0.018	0.019	0.015	0.015	0.037
Friction loss (dhF)	**Pa**	**104.7**	**0.0**	**1849.5**	**96.8**	**197.4**	**4073.5**	**153.2**	**3051.7**	**3983.9**	**396.5**
	m	**0.01**	**0.00**	**0.19**	**0.01**	**0.02**	**0.42**	**0.02**	**0.31**	**0.41**	**0.04**
Friction loss (dhm)	**Pa**	**632.2**	**0.0**	**0.0**	**1518.9**	**1708.8**	**2278.4**	**552.8**	**3291.0**	**0.0**	**0.0**
Pump head (dhP)	**Pa**	**2647.1**	**9804.1**	**0.0**	**0.0**	**6274.6**	**0.0**	**0.0**	**-588248.4**	**0.0**	**0.0**
Pressure (P1)	**Pa**	**924647**	**934451**	**49702**	**18656**	**45911**	**781090**	**941028**	**318302**	**6284**	**1101496**
Pressure (P1)	**mWG**	**94.29**	**95.29**	**5.07**	**1.90**	**4.68**	**79.65**	**95.96**	**32.46**	**0.64**	**112.32**

Figure 6 Calculated system losses. Blue is input values, yellow is calculated. Red cells highlight important considerations or warnings in the design calculation, and green cells highlight calculated values that are considered sensible. The pressure, absoute values are shown to check the system does not go below vapour pressure (assumed here to be that of water at 20°C).

APPENDIX 5.

Export Power Calculations for 30kW ECS unit **Associated Power Ltd.**

Turbine Power Output	g- m.sec	m	kPa	mwg	SG	Efficiency %	kW	m.cu.sec
			9.80665					
Media circuit height		32			3			
Back Up height		1			1			
Base Pressure		97						
Flow								0.1
Turbine infeed pressure				92.19				
g	9.81							
Base pressure				94				
Head loss in 3m x 200mm feed + reducer				0.366				
Head loss in 250mm return pipe		32		0.444				
Head loss due to magnet height				4				
Total head loss			47.16999	4.81				
Turbine + Generator Efficiency (82% + 93%)						0.76		
Net input head			856.9051	87.38				
Discharge return head			268.5061	27.38				
Net Head across turbine			588.399	60				
Turbine power output gross							**44.73**	
Deduct Pump							-7.1	
Deduct Magnet							-2	
Deduct Ancilliaries							-2	
Total deductions							-11.1	
Turbine net export power.							**33.63** kW	
Error margin 10%	3.36336 kW						**30.27 kW Export**	

Figure 7 Export Power Calculations from Appendix 5 of ECS document.

POWER

Pump of dense fluid

		Warman Pump 400L
		Note 1
Flow rate	m3/h	720
Head	m	1
Specific gravity	sg	3
Pump efficiency	%	83
Power required	kW	7.09

Turbine output

		Omega 125-365A Turbine
		Note 1,2
Flow rate	m3/h	100
Head	m	60
Efficiency	%	82
Shaft power	kW	48.25
Generator efficiency	%	93
Power output	kW	44.87

Auxillaries

		Magnet	Auxillaries
		Note 4	Note 4
Power required	kW	4	2

References

Note 1	Taken from datasheet
Note 2	Data from Appendix 5

Figure 8 NEL Calculations of known power required and output with suitable corrections.

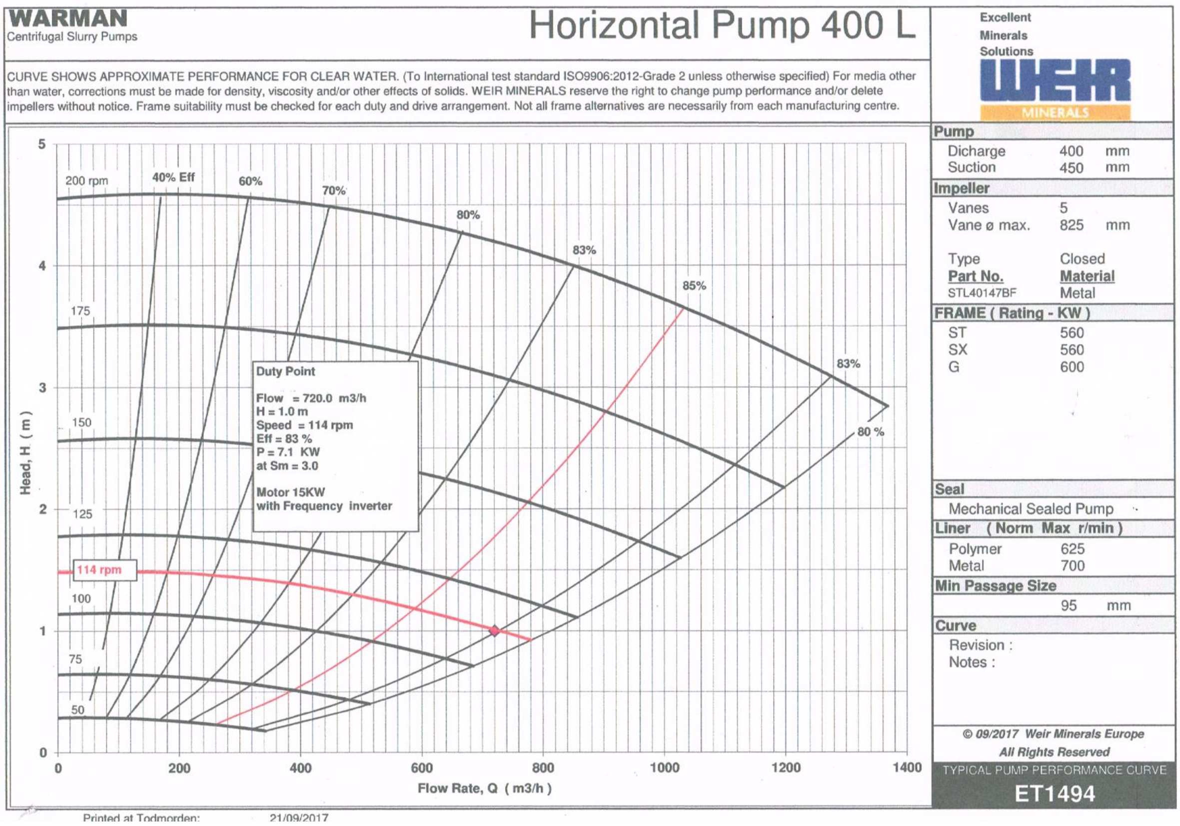

Figure 9 Additional pump curve from ECS document.

End of Report