Appendices to

ANIMAL FAT (TALLOW) AS FUEL FOR STATIONARY INTERNAL COMBUSTION ENGINES

by

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A thesis submitted to
The University of Birmingham
for the degree of
DOCTOR OF PHILOSOPHY

School of Mechanical Engineering
The University of Birmingham
March 2012

Appendices

Appendix 1 – cEGR Calculations and Technical Drawings

1. Calculation of the exhaust gases flow

   a. Assumptions / Input data

      Engine running at 75% load:

      $P = 600[kW]$

      Fuel consumption at 75% load:

      $\dot{m}_{fuel} = 145$ [kg/h] (diesel)

      Stoichiometric Air/Fuel Ratio:

      $$\left(\frac{A}{F}\right)_{stoic} = 14.5\left[{}^{kg_{air}}\!/_{kg_{fuel}}\right]$$

      Average temperature at the proposed EGR recirculation tee (measured):

      $T_{exh} = 395[°C]$

   b. Using empirical formula based on the engine power output :

      $$\dot{m}_{exh} = 1.976 \cdot P \left[{}^{kg}\!/_{h}\right]$$

      $where: P - engine\ power\ [kW]$

      $$\dot{m}_{exh} = 1.976 \cdot P = 1.976 \cdot 600 \approx 1185\left[{}^{kg}\!/_{h}\right]$$

      Calculation of the volumetric flow (reference conditions):

      $$\dot{V}_{exh\,N} = \frac{\dot{m}_{exh}}{\rho_{exh\,N}} = \frac{1185}{1.29} \approx 920\ \left[{}^{Nm^3}\!/_{h}\right]$$

      Calculation of the volumetric flow at temperature:

      $$\dot{V}_{exh\,T} = \dot{V}_{exh\,N} \cdot \frac{T_N + T_{exh}}{T_N} = 920 \cdot \frac{273 + 395}{273} \approx 2250\left[{}^{m^3}\!/_{h}\right]$$

c. Air flow based on fuel consumption

$$\dot{m}_{air} = \dot{m}_{fuel} \cdot x = 145 \cdot 14.5 \approx 2100 \left[{}^{kg}/_{h}\right]$$

Calculation of the volumetric flow (reference conditions):

$$\dot{V}_{air\,N} = \frac{\dot{m}_{air}}{\rho_{air\,N}} = \frac{2100}{1.2} \approx 1750 \left[{}^{Nm^3}/_{h}\right]$$

d. Actual reading taken at the exhaust stack – at the temperature of 300 °C

$$\dot{V}_{exh\,300} = 1950 \left[{}^{m^3}/_{h}\right]$$

After normalisation to the temperature at recirculation tee:

$$\dot{V}_{exh\,395} = 2275 \left[{}^{m^3}/_{h}\right] \qquad \dot{m}_{exh} = 1200 \left[{}^{kg}/_{h}\right]$$

2. Calculation of water requirement

a. Assumptions/Input data

Assumed max recirculation rate:

$$n_{EGR} = 40\ [\%]$$

Desired exhaust temperature:

$$T_{c\,ehx} = 100\ [°\mathrm{C}]$$

Specific heat of exhaust:

$$c_{p\,exh} = 1089 \left[{}^{J}/_{kg \cdot K}\right]$$

Specific heat of water:

$$c_{p\,H20} = 4190 \left[{}^{J}/_{kg \cdot K}\right]$$

b. Capacity required to cool specified mass of exhaust gases

$$Q = n \cdot \dot{m}_{exh} \cdot c_{p\ exh} \cdot \Delta T$$
$$Q = n \cdot \dot{m}_{exh} \cdot c_{p\ exh} \cdot (T_{ehx} - T_{c\ ehx})$$
$$Q = 0.4 \cdot 1200 \cdot 1089 \cdot (395 - 100) = 154202400 \left[{}^{J}/_{h}\right]$$

c. Calculation of water requirement

$Q_{H20} = \dot{m}_{H2O} \cdot c_{p\ H2O} \cdot \Delta T$, heat of evaporation is disregarded in this calculation,

$$\dot{m}_{H2O} = \frac{Q_{H20}}{c_{p\ H2O} \cdot \Delta T} = \frac{Q_{H20}}{c_{p\ H2O} \cdot (T_{c\ ehx} - T_{amb})}$$
$$\dot{m}_{H2O} = \frac{154202400}{4190 \cdot (100 - 20)} = 460 \left[{}^{kg}/_{h}\right] \approx 460 \left[{}^{l}/_{h}\right]$$

3. Selection of the water nozzle

BIM 11 1/8’’ nozzles manufactured by Delavan were selected for the cooling system trial. The system should be capable of delivering at least 7.7 litres of water per minute. Nozzle data are given in the attached table.

4. Nozzle testing

Selected nozzles were tested at the rig consisting of the water pump and manifold enabling installation of up to four nozzles. The pump was supplying water at a pressure of 0.8 barG. Test results are presented in the table below.

No of nozzles	Flow recorded [l/min]
1	2.65
2	4.67
3	6.67
4	8.71

5. Selection of the solution

From the calculations and test presented above it can be concluded that an injection system consisting of four injection nozzles should be capable of providing a sufficient amount of water to cool down the required proportion of exhaust gases to 100°C. To ensure additional capacity and also employ a scrubbing effect of water injection it was decided to install four injection nozzles.

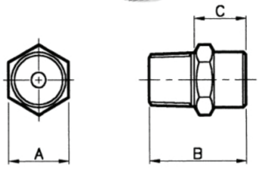
6. Achieved results

The designed system enabled the cooling of exhaust gases down to 120 °C at the recirculation rate of 25%.

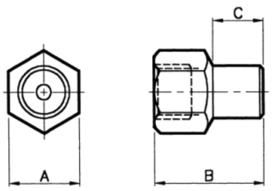
DELAVAN
Spray Technologies

TYPE BI

SOLID CONE SPRAY



BIM (MALE)



BIF (FEMALE)

Maximum Recommended Pressure: 70 Bar.G. (Metal), 7 Bar.G. (Plastic).

SPRAY CHARACTERISTICS

- *Uniform distribution of droplets in a solid cone spray pattern.*
- *Droplet size is larger than in hollow cone nozzles of equal capacity.*
- *Impact of spray is generally greater with narrower spray angles, assuming the same flow rate. Pressure increases affect spray angle.*

CONSTRUCTION AND MATERIALS

- *One piece body with pressed in cross-milled core which is removable.*
- *Core imparts the necessary swirl to produce a solid cone spray pattern.*
- *Hexagon body for easy installation, eliminates distortion of orifice during installation.*
- *Available with Male BSPT and Female BSPP threads.*
- *Brass and 316 Stainless Steel are standard.*
- *Other materials available to special order.*

ORDER EXAMPLE

1/4" BIM (Male) 22 Brass.
1/2" BIF (Female) 49 Stainless Steel.

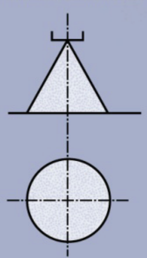
DIMENSIONS AND WEIGHTS

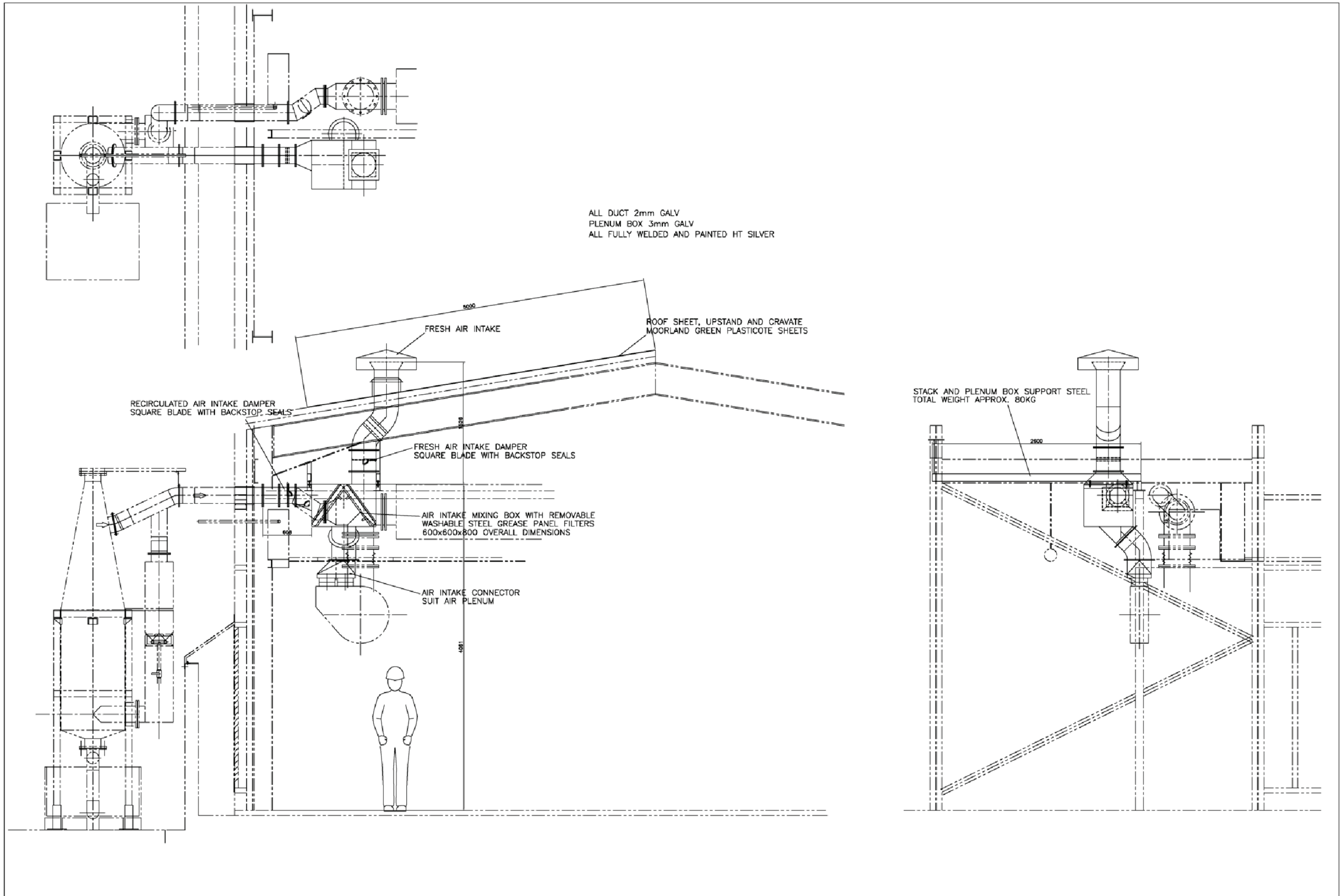
Thread Size	Nozzle Type	Dimensions (mm) A Hex	B	C	Weight (g)
1/8"	BIM	11,3	17,5	9,6	10
1/8"	BIF	15,3	25,4	13,5	21
1/4"	BIM	15,3	24,5	13,0	24
1/4"	BIF	18,0	27,8	12,7	35
3/8"	BIM	18,0	25,5	14,0	35
3/8"	BIF	20,8	38,9	21,1	58
1/2"	BIM	25,6	32,0	16,1	75
1/2"	BIF	25,6	50,0	28,3	118
3/4"	BIM	28,0	36,0	19,0	115
3/4"	BIF	31,8	62,7	31,5	215
1"	BIM	38,0	50,0	28,5	290
1"	BIF	38,0	81,0	51,0	330

CAPACITY CHART

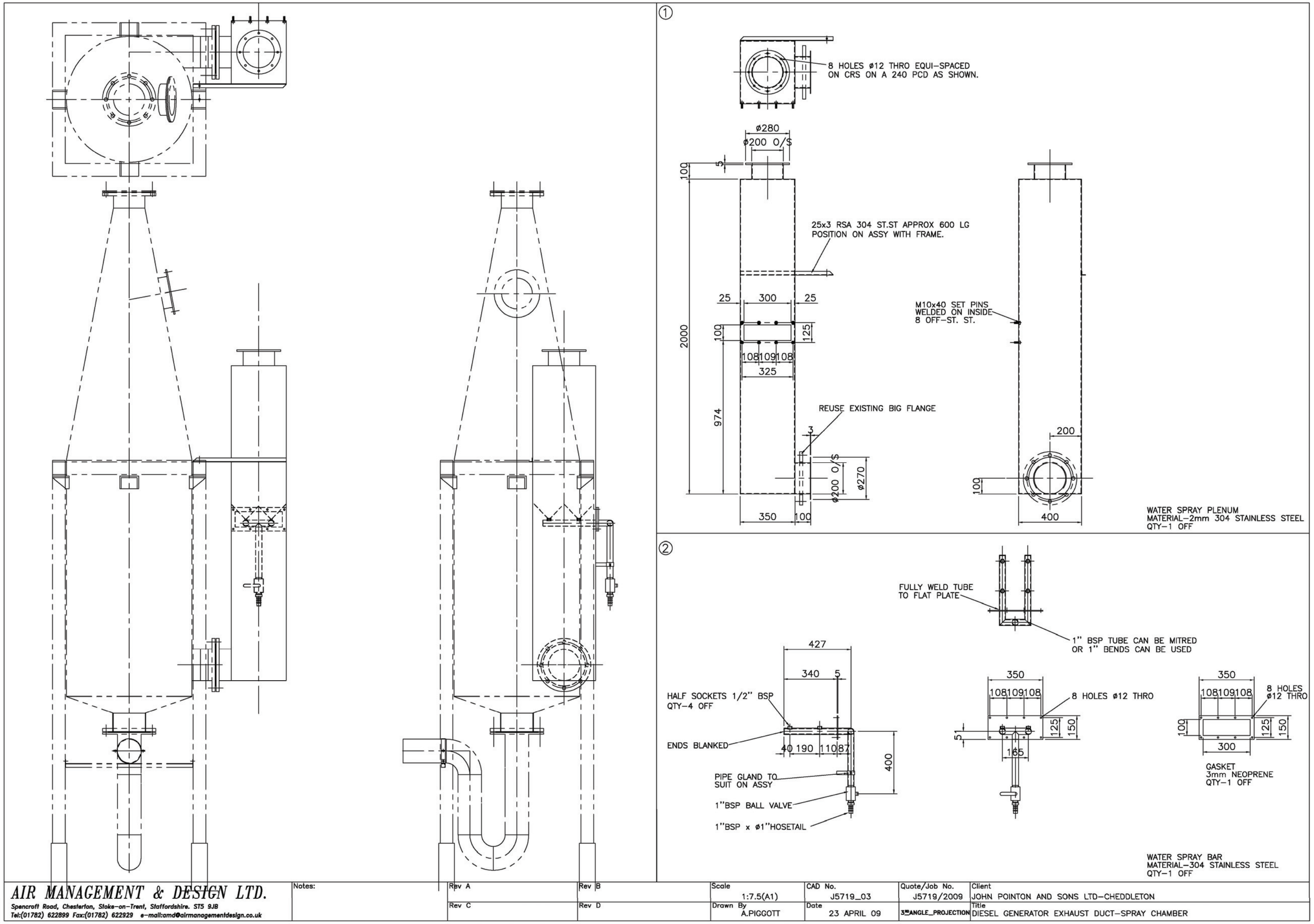
NOZZLE NUMBER		BSPT THREAD SIZE						FLOW RATE IN LITRES/MIN AT Bar.G.										SPRAY ANGLES (°) AT Bar.G.		
Female	Male	1/8	1/4	3/8	1/2	3/4	1	,35	,7	1	1,5	2	3	4	6	7	8	,7	2	6
BIF 6	BIM 6	■	■					0,88	1,25	1,50	1,88	2,18	2,65	2,87	3,41	3,54	3,76	40	47	40
BIF 8	BIM 8	■	■					1,30	1,86	2,28	2,84	3,23	4,00	4,55	5,38	5,72	5,97	44	56	53
BIF 11	BIM 11	■	■					1,63	2,32	2,87	3,62	4,05	4,87	5,36	6,30	6,74	7,06	52	64	58
BIF 12	BIM 12	■	■					2,09	2,79	3,41	4,09	4,55	5,30	5,91	7,02	7,58	8,01	62	70	58
BIF 16	BIM 16		■					2,50	3,58	4,41	5,30	6,14	7,27	8,00	9,51	10,04	10,61	57	60	55
BIF 20	BIM 20		■					3,11	4,46	5,46	6,50	7,54	9,06	10,00	11,92	12,63	13,43	62	73	58
BIF 22	BIM 22		■					3,58	5,11	6,24	7,51	8,32	9,78	10,91	13,23	14,24	14,95	70	80	62
BIF 12	BIM 12			■				2,00	2,79	3,32	4,19	4,73	5,83	6,60	7,79	8,17	8,65	36	45	39
BIF 16	BIM 16			■				2,50	3,58	4,41	5,30	6,14	7,27	8,00	9,51	10,04	10,61	57	60	55
BIF 20	BIM 20			■				3,11	4,46	5,46	6,50	7,54	9,06	10,00	11,92	12,63	13,43	61	73	58
BIF 22	BIM 22			■				3,58	5,11	6,24	7,51	8,32	9,78	10,91	13,23	14,24	14,95	70	80	62
BIF 27	BIM 27			■				4,23	6,04	7,42	9,01	10,10	12,32	13,64	16,06	17,47	18,08	44	53	51
BIF 32	BIM 32			■				5,81	7,25	8,88	10,81	12,32	14,44	15,96	19,29	20,40	22,12	60	70	61
BIF 27	BIM 27				■			4,23	6,04	7,42	9,01	10,10	12,32	13,64	16,06	17,47	18,08	44	53	51
BIF 32	BIM 32				■			5,81	7,25	8,88	10,81	12,32	14,44	15,96	19,29	20,40	22,12	60	70	61
BIF 42	BIM 42				■			6,74	9,67	11,82	14,44	15,96	19,29	21,41	24,95	27,37	28,48	70	76	64
BIF 49	BIM 49				■			8,17	11,62	14,24	16,36	18,69	23,13	25,05	29,29	32,52	33,94	79	86	72
BIF 63	BIM 63				■			10,20	14,44	17,07	20,50	23,84	28,89	32,22	38,48	41,31	43,94	70	80	70
BIF 47	BIM 47					■		7,48	10,61	13,03	14,95	17,78	21,11	26,63	28,48	30,20	31,71	43	57	42
BIF 63	BIM 63					■		10,20	14,44	17,07	20,50	23,84	28,89	32,22	38,48	41,31	43,94	60	69	53
BIF 77	BIM 77					■		12,32	17,68	20,50	23,94	29,09	34,95	38,68	45,65	49,29	52,02	70	73	60
BIF 89	BIM 89					■		13,94	20,00	23,74	29,39	33,63	40,00	44,54	52,92	56,26	59,29	82	85	67
BIF 102	BIM 102					■		14,85	20,91	27,37	33,73	38,68	46,26	50,00	60,10	64,54	67,87	85	97	74
BIF 73	BIM 73						■	11,92	16,26	20,00	22,62	27,78	34,24	38,68	45,65	50,00	52,02	35	41	44
BIF 105	BIM 105						■	16,26	23,23	27,78	33,73	39,79	48,18	52,32	62,42	67,37	71,51	51	57	49
BIF 123	BIM 123						■	19,49	28,38	34,64	42,32	46,56	57,77	63,63	75,95	80,40	85,55	66	73	57
BIF 140	BIM 140						■	22,73	32,02	38,18	45,25	53,23	62,12	68,18	80,80	85,95	90,90	75	81	52
BIF 162	BIM 162						■	25,55	36,26	44,64	53,03	61,41	72,22	79,08	95,14	101,00	108,07	74	86	63
BIF 193	BIM 193						■	28,79	41,81	50,10	60,70	73,23	87,57	99,08	119,18	128,27	135,34	82	100	80

Contact our Helpline for any special requirements:
Tel: +44 (0) 151 424 6821
Fax: +44 (0) 151 495 1043
e-mail:sales@delavan.co.uk
Web:www.delavan.co.uk





AIR MANAGEMENT & DESIGN LTD.	Notes:	Rev A	Rev B	Scale 1:7.5(A1)	CAD No. Q5855/2009	Quote/Job No. QUOTE/2009	Client JOHN POINTON AND SONS LTD–CHEDDLETON
Spencroft Road, Chesterton, Stoke–on–Trent, Staffordshire. ST5 9JB Tel:(01782) 622899 Fax:(01782) 622929 e–mail:amd@airmanagementdesign.co.uk		Rev C	Rev D	Drawn By A.PIGGOTT	Date 13 MAY 09	3RD ANGLE_PROJECTION	Title DIESEL GENERATOR INLET DUCT



8 HOLES ø12 THRO EQUI-SPACED ON CRS ON A 240 PCD AS SHOWN.
ø280
ø200 O/S
25x3 RSA 304 ST.ST APPROX 600 LG POSITION ON ASSY WITH FRAME.
M10x40 SET PINS WELDED ON INSIDE 8 OFF-ST. ST.
REUSE EXISTING BIG FLANGE
WATER SPRAY PLENUM
MATERIAL-2mm 304 STAINLESS STEEL
QTY-1 OFF
FULLY WELD TUBE TO FLAT PLATE
1" BSP TUBE CAN BE MITRED OR 1" BENDS CAN BE USED
HALF SOCKETS 1/2" BSP QTY-4 OFF
ENDS BLANKED
PIPE GLAND TO SUIT ON ASSY
1"BSP BALL VALVE
1"BSP x ø1"HOSETAIL
8 HOLES ø12 THRO
GASKET
3mm NEOPRENE
QTY-1 OFF
WATER SPRAY BAR
MATERIAL-304 STAINLESS STEEL
QTY-1 OFF
AIR MANAGEMENT & DESIGN LTD.
Spencroft Road, Chesterton, Stoke-on-Trent, Staffordshire. ST5 9JB
Tel:(01782) 622899 Fax:(01782) 622929 e-mail:amd@airmanagementdesign.co.uk
Notes:
Rev A
Rev B
Rev C
Rev D
Scale 1:7.5(A1)
CAD No. J5719_03
Quote/Job No. J5719/2009
Client JOHN POINTON AND SONS LTD-CHEDDLETON
Drawn By A.PIGGOTT
Date 23 APRIL 09
3RD ANGLE PROJECTION
Title DIESEL GENERATOR EXHAUST DUCT-SPRAY CHAMBER

Appendix 2 – Feasibility price estimates for FFA removal systems including Artisan Rototherm® E evaporators.

Engineering and Manufacturing

FEASIBILITY PRICE ESTIMATES

FOR

FFA REMOVAL SYSTEMS

INCLUDING

ARTISAN ROTOTHERM® E EVAPORATORS

Robert DiLoreto, Jr.
Engineering Manager

James R. Steeves
Project Engineer

73 POND STREET, WALTHAM, MA 02451-4594 USA · Phone (781) 893-6800 · Fax (781) 647-0143
Email info@artisanind.com · www.artisanind.com

1.0 TECHNICAL SECTION

1.1 Design Basis

The system is designed to reduce FFA content in biodiesel feedstock to less than 1 wt% while yielding marketable FFA product.

1.2 Process Description

(Please refer to the Process Flow Diagram in the Appendix)

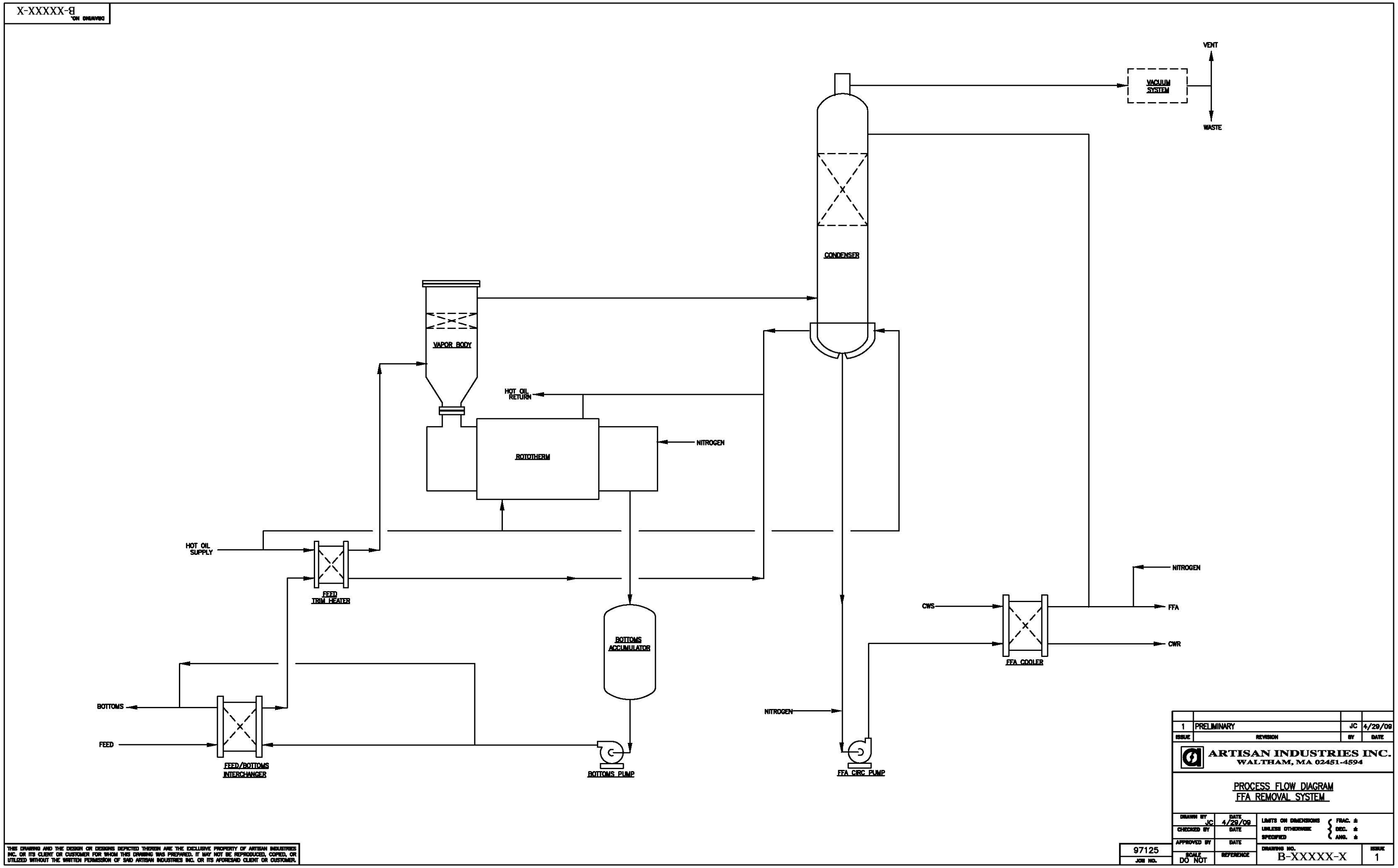
In this process, high FFA content crude feedstock is pumped through a feed/bottoms interchanger and a trim heater to preheat it, while also cooling the stripped product oil (bottoms) to its desired temperature. The preheated feed enters a vapor/liquid separator, operating under vacuum. There a portion of the FFA as well as any moisture present is flashed off. The remainder falls by gravity into the mechanically aided Artisan Rototherm® thin film evaporator where the centrifugal force generated by the spinning rotor maintains a thin film of material on the heated wall, evaporating essentially all the remaining FFA. The product gravity discharges from the Rototherm to an insulated bottoms accumulator, from which it is pumped through the feed/bottoms interchanger before entering the biodiesel process.

The Rototherm is designed with a counter-current liquid/vapor flow configuration to maximize mass transfer and minimize entrainment. Turbulence created by the rotor blades constantly renews the film, aiding in both heat and mass transfer, enabling nearly complete removal of the FFA, while preserving the quality of the stripped oil. Heating of the Rototherm is by heat transfer oil at up to 600ºF. Nitrogen at very low rates is continuously sparged into the evaporator to aid in stripping. The FFA vapor from the evaporator combines with the pre-flashed vapor, passes through a mesh entrainment separator in the vapor/liquid separator and enters the condensing system.

The FFA condensing system consists of a vertical packed column direct contact condenser with an integral accumulator, a circulating pump, and a cooler. Liquid FFA falling through the packed bed is in direct contact with rising FFA vapor, thereby condensing all but a trace amount of FFA which is carried in the gas stream to the vacuum system. A mesh entrainment separator pad is installed above the packed bed to minimize potential entrainment. The recovered FFA is pumped from the accumulator to the cooler, from which a portion is returned to the condenser and the remainder delivered to storage or further processing. At startup, a hot oil side stream from the evaporator's heating loop is used to heat the bottom of the accumulator to warm up FFA to a suitable operating temperature. Vacuum will be provided by a series of mechanical blowers followed by a liquid ring pump utilizing stripped oil or soybean oil as the ring liquid.

1.3 Scope of Supply

- Plate and frame heat exchanger for use as feed/bottoms interchanger.
- Plate and frame heat exchanger for use as a trim heater.
- Rototherm E countercurrent horizontal agitated thin film evaporator
- Bottoms accumulator tank
- Vapor body with entrainment separator
- Packed bed direct contact condenser with integral accumulator, entrainment separator and external heating coil



B-XXXXX-X
DRAWING NO.
VENT
VACUUM SYSTEM
WASTE
CONDENSER
VAPOR BODY
HOT OIL RETURN
ROTOTHERM
NITROGEN
HOT OIL SUPPLY
FEED TRIM HEATER
NITROGEN
CWS
FFA
CWR
FFA COOLER
BOTTOMS ACCUMULATOR
BOTTOMS
FEED
FEED/BOTTOMS INTERCHANGER
BOTTOMS PUMP
NITROGEN
FFA CIRC PUMP
1
PRELIMINARY
JC
4/29/09
ISSUE
REVISION
BY
DATE
ARTISAN INDUSTRIES INC.
WALTHAM, MA 02451-4594
PROCESS FLOW DIAGRAM
FFA REMOVAL SYSTEM
DRAWN BY
JC
DATE
4/29/09
CHECKED BY
DATE
APPROVED BY
DATE
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRAC. ±
DEC. ±
ANG. ±
97125
JOB NO.
SCALE
DO NOT
REFERENCE
DRAWING NO.
B-XXXXX-X
ISSUE
1
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Appendix 3 – Certificates of Analysis

A. NORMAN TATE & CO LTD.
ALEX STEWART [AGRICULTURE] ANALITICAL SERVICES

CERTIFICATE OF ANALYSIS

Cert. No: L21570

Date Reported: 05/03/2009

Date Started: 16/02/2009

Date Received: 09/02/2009

For: JOHN POINTON & SONS LTD
FELTHOUSE LANE
CHEDDLETON
STAFFS
STAFFORDSHIRE
ST13 7BT
ENGLAND

Labelled: Commodity: Tallow. Colour: Dark.

Sealed:

The following are the results of our analysis of the above described sample:

Density @40°C	0.8968 kg/L
Kinematic Viscosity @ 100°C	0.147 cSt
Flash Point	255 °C
Ash	0.09 %
Water Content	0.58 %
Sulphur	<10 Mg/Kg
Vanadium	<1 mg/kg
Aluminium	22 mg/kg
Calcium	111 mg/kg
Lead	<1 mg/kg
Total Acid Number	15.04 mg KOH/g
Sodium (10 mg/kg)	80 mg/kg
Potassium (10 mg/kg)	14 mg/kg

For A Norman Tate

FOSFA INTERNATIONAL
SCIENTIA COMMERCIIS AUXILIUM FERAT
UNIT 21 SEFTON BUSINESS PARK, NETHERTON, LIVERPOOL, MERSEYSIDE L30 1RD, ENGLAND
TEL: +44 (0) 151 525 1488 Fax: +44 (0) 151 530 1563 www.alexstewartagriculture.com

DET NORSKE VERITAS

TEST REPORT

From : DNV Petroleum Services, Norway
Our ref. : N109000691-DATRO
Name : WARTSILA FINLAND

Sample Information

Sample number : N109000691
Product type : Bio Oil
Description : Animal Fat - Tallow
Sample container : Plastic, Non DNV, no seal

Test Results

Test	Unit	Method	N109000691
Density @ 15°C	kg/m3	ISO 12185	915.5
Viscosity @ 40°C	mm^2/s	ISO 3104	42.52
Viscosity @ 80°C	mm^2/s	ISO 3104	12.19
Water Content	% V/V	ASTM D6304-C	0.30
Micro Carbon Residue	% m/m	ISO 10370	0.63
Sulfur	% m/m	ISO 8754	0.05
Total Sediment Potential	% m/m	ISO 10307-2	<0.01
Total Sediment Existent	% m/m	ISO 10307-1	0.01
Ash	% m/m	LP 1001	0.08
Vanadium	mg/kg	ISO 10478 Ext.	<1
Sodium	mg/kg	ISO 10478 Ext.	108
Aluminium	mg/kg	ISO 10478	<1
Silicon	mg/kg	ISO 10478	<1
Iron	mg/kg	ISO 10478 Ext.	33
Nickel	mg/kg	ISO 10478 Ext.	<1
Calcium	mg/kg	ISO 10478 Ext.	15
Magnesium	mg/kg	ISO 10478 Ext.	3
Lead	mg/kg	ISO 10478 Ext.	<1
Zinc	mg/kg	ISO 10478 Ext.	3
Phosphorus	mg/kg	ISO 10478 Ext.	47
Potassium	mg/kg	ISO 10478 Ext.	91
Flash Point	°C	ISO 2719-A	>230
Pour Point	°C	ISO 3016	27
Cold Filter Plugging Point *	°C	IP 309	34
Strong Acid Number	mg KOH/g	ASTM D664	0.00
Acid Number	mg KOH/g	ASTM D664	70.30
Copper Corrosion @ 50°C	-	ASTM D130	1A
Carbon	% m/m	ASTM D5291	76.94
Nitrogen	% m/m	ASTM D5291	<0.3
Hydrogen	% m/m	ASTM D5291	12.38
Oxygen	% m/m	ASTM D5291 Ext.	10.01
Gross Heat of Combustion	MJ/kg	ASTM D240	38.89
Iodine Value	-	ISO 3961	52.2
Steel Corrosion 20°C	-	LP 2902	NO CORR.
Steel Corrosion 60°C	-	LP 2902	NO CORR.
Steel Corrosion 120°C	-	LP 2902	NO CORR.

Calculated Results

Net Heat of Combustion	MJ/kg	ASTM D240	36.26

Comment:
*Cold Filter Plugging Point - internal test method. Sample tested as received (not filtered). Prior to testing heated to 60°C. The temperature in cooling bath 0°C. The test started at 50°C. Tested every 2°C.
Cloud Point – not possible due to nature of sample (dark brown).

Appendix 4 – Summary of the KTP Project

The host company – John Pointon & Sons Ltd. have acquired the following knowledge and capabilities as a result of the KTP project:

- Electrical generation on-site.
    - Understanding Electrical Protection Systems (HV protection)
    - Trained as Senior Authorised Person to issue documentation i.e. High Voltage Permit to Work, Sanction for Test etc.
    - Maintenance of a diesel engine and generator.
    - Condition monitoring of fuel systems, combustion, cooling system, cylinder pressures (high speed pressure transducers + computer interfaces)
- Economic variables.
    - Assessing tallow price fluctuations as a tradable commodity (economic feasibility of tallow as a fuel)
    - Maintenance costs (oil usage, man power requirements, maintenance frequency)
    - Repair costs and evaluation of failures to find route causes.
- Environmental
    - Monitoring/recording of exhaust emissions at all stages of the project.
    - Modifying the design of the exhaust path to reduce various chemical components in the exhaust gases.

Although the project had its mechanical problems i.e. piston failures due to possible inherent piston design - the overall testing suggested that tallow was a viable fuel and with modifications to the fundamental engine configuration i.e. EGR (Exhaust Gas Recirculation) fitted with cooling, helped to improve some of the emission levels. It was an encouraging experiment which the company feels will be useful for any future developments in the generation of electricity using tallow as the prime source of fuel. Additionally, during the analysis of tallow's properties, it was identified as having extremely good lubricating characteristics - this observation could be developed in the future, as a possible additive in other novel fuels.

Electricity consumption was reduced from the supplier by approx £76,000 over the generation period.

The KTP has sadly had to be shortened due to the financial circumstances of John Pointon and Sons i.e. the company had to make several redundancies and halt all capital projects during the final year of the KTP.

Other than the financial circumstances, the KTP worked extremely effectively and the company would like to thank all those involved (147).