Fuel Flow Metering for Fishing Vessels

Phase-1 Preliminary Report

prepared for:

The Sea Fish Industry Authority

with support from:

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August 2008

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Introduction

In June 2008, the University of Exeter was invited to submit a proposal to conduct testing of the accuracy of fuel meters for fishing boats, on behalf of the Sea Fish Industry Authority. Subsequently, the proposal was approved and an order was received for the work on 11 July 2008.

The rationale supporting the need for such work is that in times of elevated fuel prices, the single most important piece of economic feedback the skipper of a fishing vessel can receive on the bridge, is a real time value of fuel flow rate to the engine. Providing an instantaneous fuel consumption meter would reinforce fuel consumption feedback to the skipper that would allow her or him to quickly quantify the effects of her or his actions taken to attempt to improve fuel economy – providing that that feedback is accurate. If the feedback is not accurate, measures taken by skippers could actually lead to deterioration in fuel economy rather than improvement. Thus it is crucial that the fuel flow metering options for fishing vessels be assessed for their accuracy and reliability, in order that the best possible information is provided to the skipper. As ever, there is an economic aspect to this issue too. Clearly, without the study, it would be possible to identify a very accurate fuel flow meter that will be appropriate, but how much would it cost? Then the central questions then are:

- What is the most accurate way to meter fuel consumption on an in-service fishing vessel?
- Can this be provided at reasonable cost to fishermen?
- How straightforward will the device be to fit on a fishing vessel?
- How long is the sensor likely to last given the demanding environmental conditions on board fishing vessels?

To answer these questions, the proposed research was divided into four phases:

- Phase 1 – Desk study
- Phase 2 – Offline accuracy and repeatability experiments
- Phase 3 – Engine installation and assessment of in-service performance
- Phase 4 – Evaluation and Deliverables

The objective of the Phase 1 work was to assess the available technology in terms of quoted specification, cost, transducer type and installation requirements, with a view to selecting devices to test. Work on Phase 1 formally started on 21 July 2008 and the agreed duration for the complete project was 2-3 months. From early discussions with suppliers of fuel flow meters, it became apparent that lead times for the supply of certain meters could be as much as one month. Given the proposed project duration and these supply times, it was vital to expedite decisions on which fuel meters would be tested within the programme.

This report summarises findings thus far during Phase 1 of the work, to allow devices with long supply lead times to be ordered in time to ensure the project will complete to schedule. Decisions made on the devices to be tested are reported herein. These devices were selected in consultation with a representative SeaFISH during a meeting held on 24th July. As it is presented at a very preliminary stage of the work, it should be appreciated that the materials presented herein may be revised by the time of presentation of the final project report. The research team have already encountered one result that will significantly effect the direction of the work.

Key factors in selection of fuel flow-rate measurement devices

The project team identified the following set of factors that were used to screen the multiplicity of commercially available fuel flow rate measurement devices. These were used to help the team to select devices most applicable to installation on diesel engines of fishing vessels to meter the fuel supplied to, and returned from, a marine diesel engine.

Volumetric flow range

There are two key determinants of the rating of the flowrate sensor to provide instantaneous fuel consumption rate to the bridge of a fishing vessel. Firstly, the greater the rating of output power of the engine, the greater the fuel it will consume at maximum power. This information, together with an estimate of the efficiency of the engine under full load, allows the fuel consumption rate under this condition to be estimated (Table 01, column 7). This may not be the highest value of flow rate that the sensor will have to measure. It is equally important to establish the key purpose of the return fuel flow line in specific installations. For many diesel engines, particularly smaller models, there is very little return flow to the fuel tank. The return fuel line is installed to provide an escape way for any air bubble that may be blocking the system, and to allow the fuel supply system to be bled. Engines that are designed for zero return flow may in fact deliver non-zero, but small, flow rates, if they have suffered appreciable wear. However, for other models of engine, typically larger units, the fuel supplied to the engine injectors is designed to cool the injectors, waste heat being dumped to the fuel tanks. In this case appreciable flow rates of fuel may be returned to the fuel tanks, at magnitudes possibly 300% of the fuel consumption rate. In these cases the full scale deflection (FSD) value of a flow meter must be rated on the return flow volumes. In Table 01, column 8, for the purposes of sensor selection, it has been assumed that this could be as much as 3.5 times the fuel consumption rate.

Table 01: Guideline fuel consumption rates at maximum power for a range of engine ratings

Engine size		Max load Efficiency	Fuel Power	Fuel consumption rate			Max FSD flowrate
				Energy	Mass	Volume	
(hp)	(kW)	(%)	(kW)	(kWh/h)	(kg/h)	(litres/h)	(litres/h)
100	75	34	221	221	17.8	20.7	72.4
250	187.5	34	551	551	44.4	51.7	181.1
500	375	34	1103	1103	88.8	103.5	362.1
1000	750	34	2206	2206	177.6	206.9	724.3
1500	1125	34	3309	3309	266.4	310.4	1086.4

When the return flow line is in fact used to return appreciable amounts of fuel while the engine is in service, two flow meters will be required. It is also important to recognise that in these instances two meters with different FSD may have to be selected, depending on the relative flow rates in feed and return lines.

Physical Properties of Fuel

Conductivity

Electromagnetic flow meters measure flow by passing a current through fluid. In general electromagnetic meters require the electrical conductivity of the fluid being measured to be above 5 μS/cm. Since diesel is a poor conductor (conductivity in the range of pS/m – see Figure 01) these meters are unsuitable for a diesel fuel metering application.

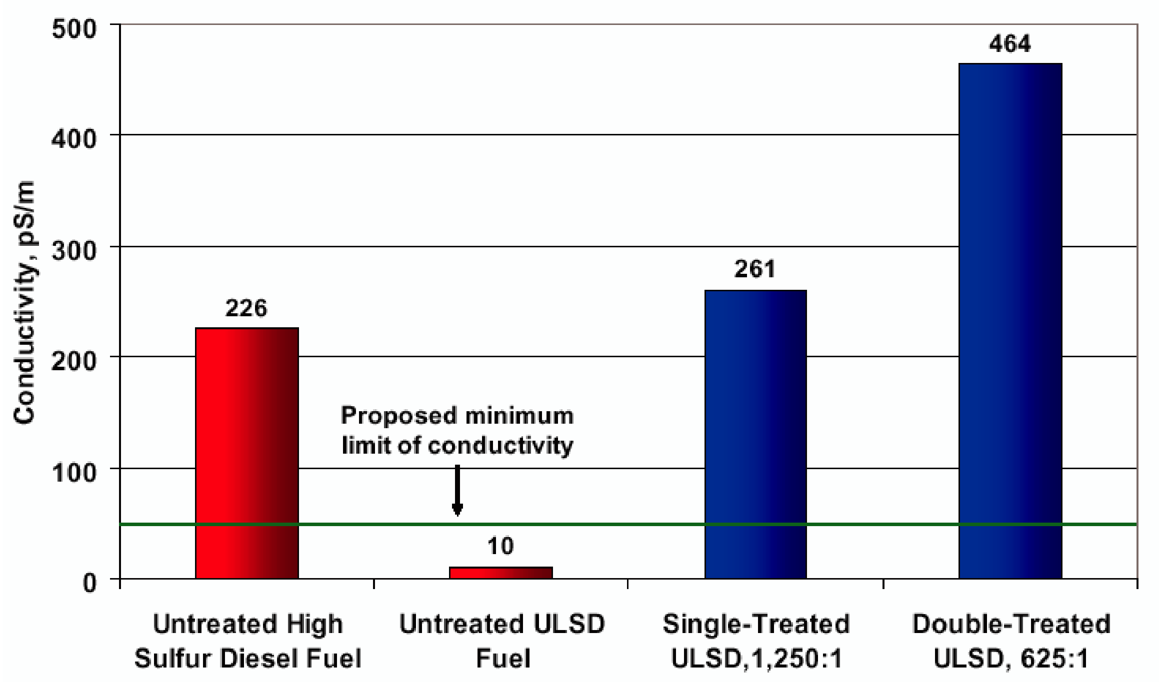

Figure 01: Conductivity of diesel fuel (Source: www.envirofuelsllc.com).

Viscosity

Manufacturers of certain types of flow meter design their meters for fluids with defined ranges of viscosity. The variation of the viscosity of diesel and other fuels are presented in Figure 02.

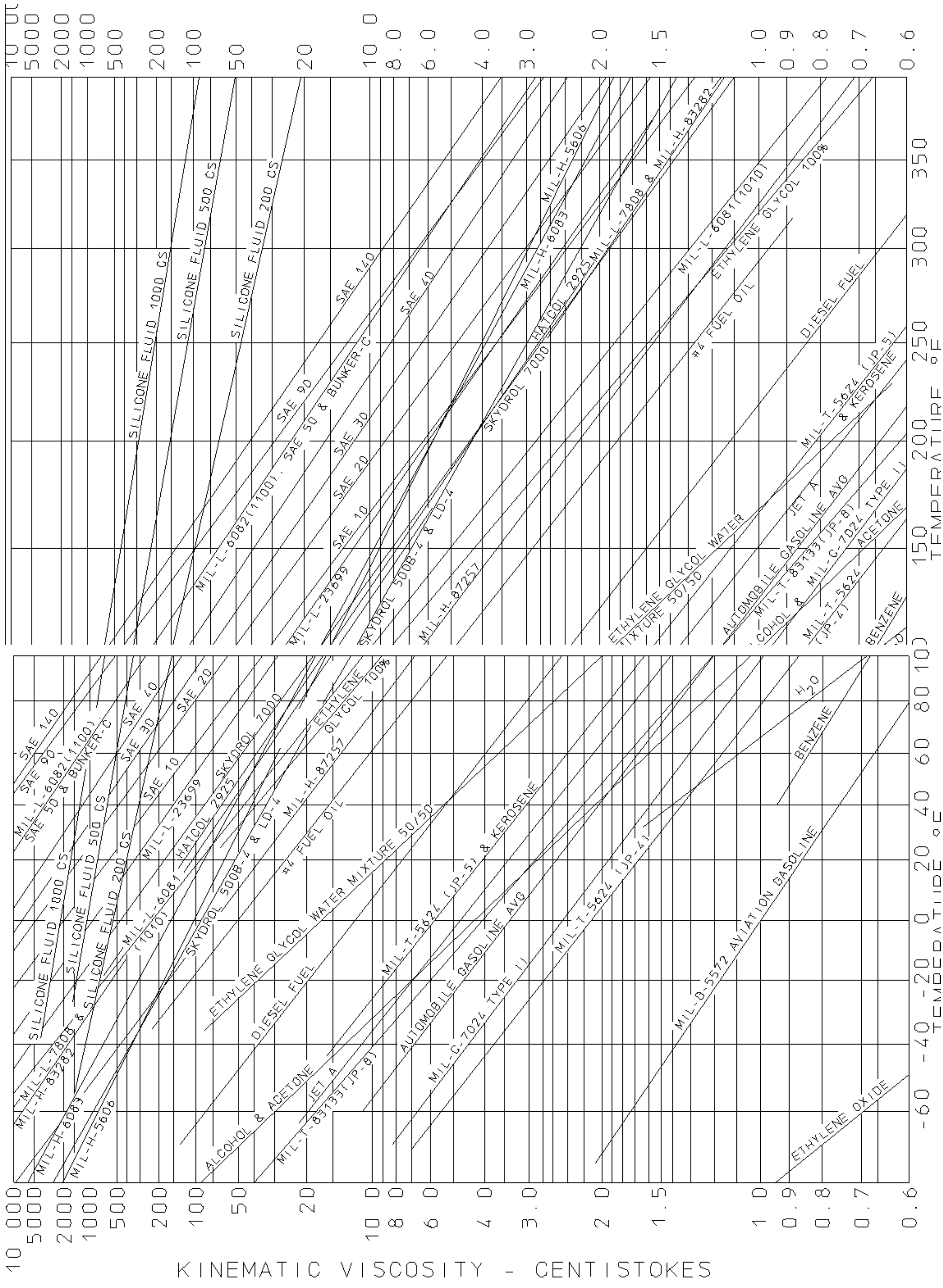

Figure 02: Variation of viscosity with temperature for various fuels (Source: http://www.microhydraulics.com/LEEWEB2.NSF/1c6397740f8b45e1852563b9006d6bc6/4fb2037fc902397a8525689b00654b3a?OpenDocument

Thermal expansion

Fuel temperature can vary in service due to environmental and operating conditions. Figure 03 shows that, approximately, a 10ºC change in temperature will lead to a 0.84% change in volume. Flow meters operating by directly measuring volume or velocity will require temperature correction to reduce fuel consumption to a mass flow basis in order that fuel consumption performance can be compared from day-to-day and season-to-season.

When significant volumes of fuel are returned to the fuel tank, this is sometimes due to the fact that the fuel is used to cool the injectors. Temperature correction of fuel volumes will be required in this instance too, to determine fuel consumption by taking differences between two meter readings.

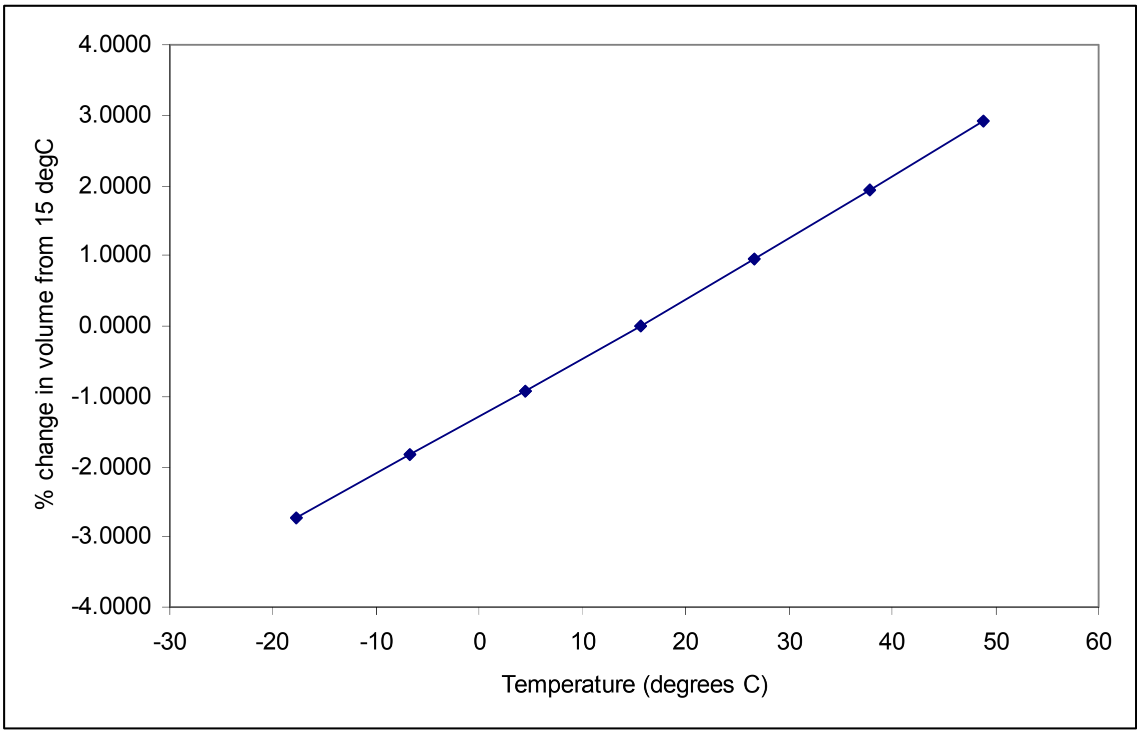

Figure 03: Thermal expansion behaviour of diesel fuel

Other selection factors

- **Cavitation.** Due to the rapid depressurisation of fuel in the injection system it is feasible that vapour bubbles in liquid fuel could be returned through the recovery lines.
- **Pulsation.** The flow regime is unsteady and will pulse with a frequency proportional to the frequency of fuel injection.
- **Chemical properties of the fuel.** Flow meters can be designed for use with specific liquids with particular chemical reactivity to minimise degradation of meter components.
- **Environment.** The meter(s) will be subject to constant motion and vibrations.
- **Supply Head.** The meter(s) should not drop more head than can be handled by the fuel lift pump. The lift pump pressure on the CSM dynamometer test engine is 6-10 psi (0.7 bar).

Types of flow measurement device

Positive Displacement flowmeters

These meters measure flow-rate based on volumetric displacement of fluid. They remain accurate at small fractions of rated capacity, but have relatively high head-losses; therefore they are generally suited to higher flow-rates. Mechanical parts of the meter are exposed to the fuel. If these were prone to wear or failure, such an event could potentially cause obstructed fuel flow. For this reason, the fuel meter should be installed with a by-pass leg. Examples of positive displacement flow meters include: oval gear flow meters, reciprocating piston flow meters, and nutating discs (wobble meters).

These flow meters repeatedly entrap the fluid to measure its flow. By measuring the number of entrapments in a given time, and with knowledge of the entrapment volume, the volumetric flow rate can be determined. The measured fluid must be clean and free from vapour or bubbles.

Oval gear positive displacement flow meter

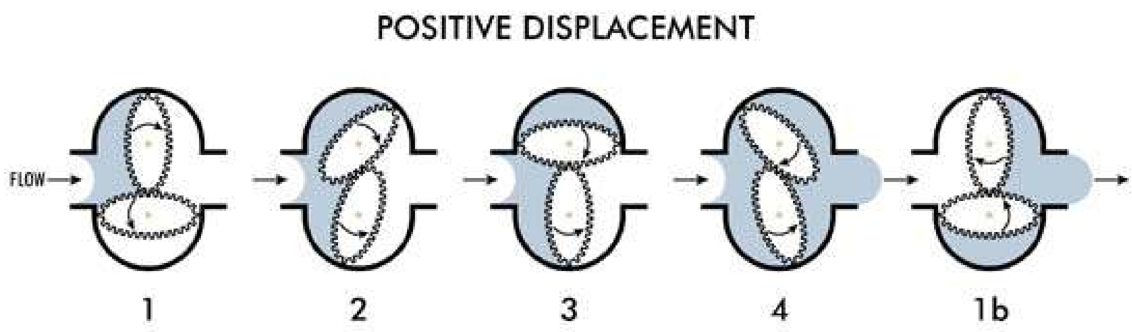

Figure 04: Principle of operation of an oval gear positive placement flow meter. (Source: www.flowmeters.com)

Nutating disc flow meters

These meters have a moveable disk mounted on a concentric sphere located in a spherical side-walled chamber. The pressure of the liquid passing through the measuring chamber causes the disk to rock in a circulating path without rotating about its own axis. It is the only moving part in the measuring chamber. A pin extending perpendicularly from the disk is connected to a mechanical counter that monitors the disk's rocking motions. Each cycle is proportional to a specific quantity of flow. As is true with all positive-displacement meters, viscosity variations below a given threshold will affect measuring accuracies. (www.maxiflo.co.kr)

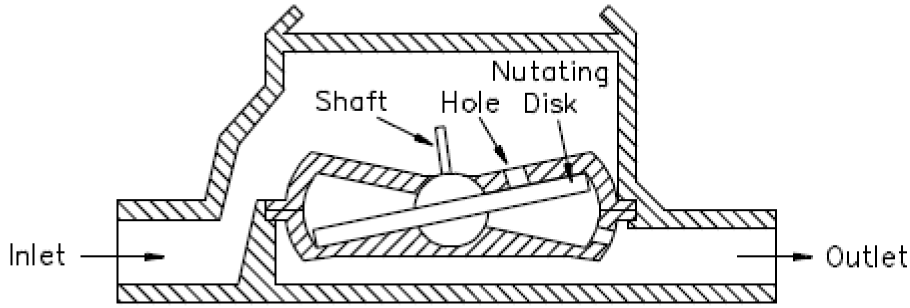

Figure 05: Section through a nutating disc flow meter. (source: www.flowmeters.com)

Rotary-vane meters

The basic unit consists of an equally divided, rotating impeller (containing two or more compartments) mounted inside the meter's housing. The impeller is in continuous contact with the casing. A fixed volume of liquid is swept to the meter's outlet from each compartment as the impeller rotates. The revolutions of the impeller are counted and registered in volumetric units.

Inferential flow meters

Inferential flow meters do not sense flow rate through the direct measurement of a flow variable (volume, velocity or mass). Instead they estimate flow by inferring its value from other measured parameters. Examples of flow meter technologies that measure inferentially include differential pressure meters, target meters and variable area flow meters.

Differential Pressure

Creates a pressure drop across a restriction or orifice, the magnitude of which indicates the velocity via Bernoulli's Equation. They incur a relatively large head-loss, proportional to flow-rate. No mechanical moving parts are immersed in fluid flow. Pulsating flow presents problems when deriving velocity from differential head, due to their 2nd order relationship, although this can be overcome with a relatively high data acquisition frequency and software for post processing.

Figure 06: McCrometer Venturi-V-cone differential pressure flow transducer. (Source: www.flowline.co.uk/)

Variable Area

Variable area flow meters measure flow by maintaining a constant pressure drop across a variable aperture restriction. Head loss is essentially constant across a range of flow-rates. Float-type variable aperture meters are not suitable for use on a vessel due to the fact that they must be vertical when the restoring force is simply the weight of the float.

Spring-opposed float designs allow this type of flow meter to be installed in horizontal pipes, because the functioning of the float is not dependent upon gravity. Frequently, these flow meters can be read locally because their glass or plastic metering tubes have markings that relate the height of the float (that can be seen) with the flow rate of the fluid. However, some instances of this type of flow meter are constructed in metal, such as stainless steel, that include an electronic transmitter that senses the displacement of the 'float' to determine fluid flow. This type of flow meter should not be used when there is potential for the metered fluid to 'coat' the metering tube or float.

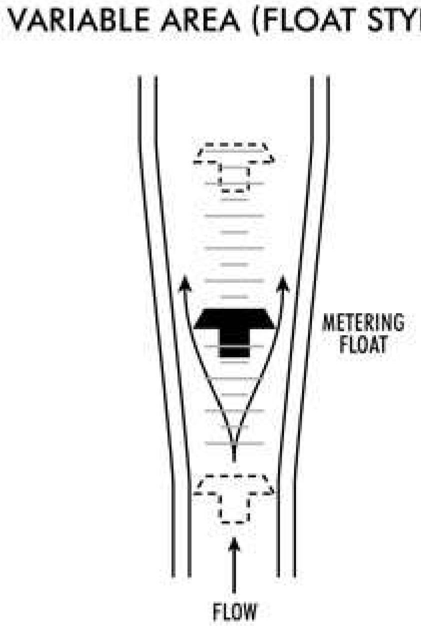

Figure 07 Variable area float flow meter (www.flowmeters.com)

Velocity sensing flow meters

Turbine flow meters

Turbine flow meters estimate flow rate based on fluid velocity and knowledge of the internal diameter close to the installation. These meters comprise a multiple bladed, free spinning rotor and a magnetic pick up that senses a frequency signal that is proportional to the flow rate. Although they have a low response time to flow fluctuations, mechanical inertia under pulsating flows may reduce the accuracy of measurements. Mechanical parts are exposed to the fuel and are prone to wear, however, the rotors do not obstruct flow in the event of failure.

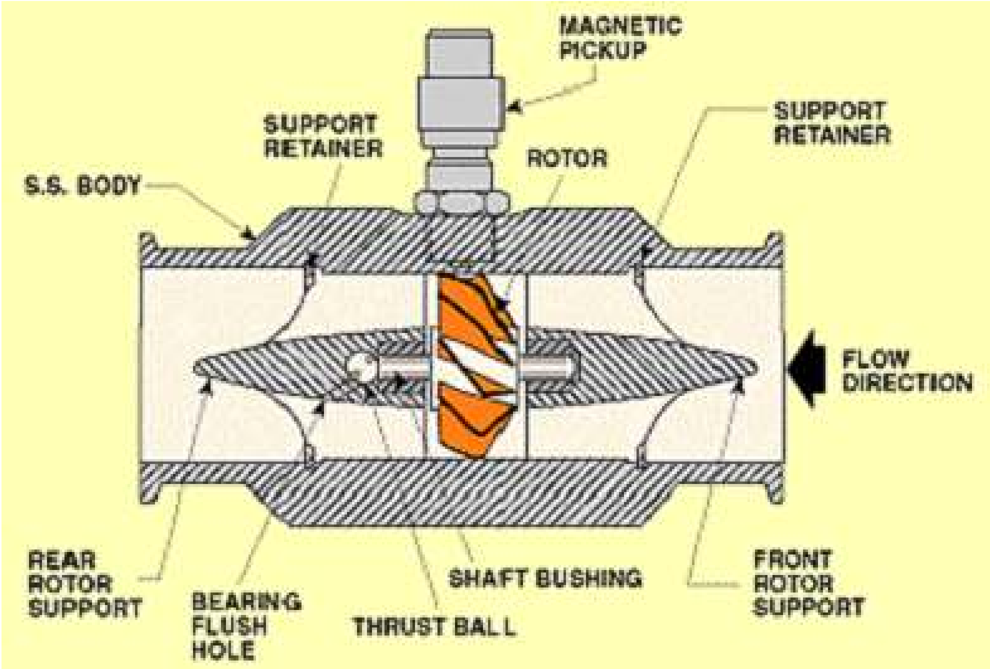

Figure 08: Turbine flowmeter (www.omega.com).

Figure 09: Inline turbine meter supplied by Flowline limited (Source: www.flowline.co.uk/).

Ultrasonic

Ultrasonic meters measure flow velocity from observations on a sonic wave passed through the flowing fluid, that exploit either a Doppler effect or time-of-flight principle. In general these meters are non-intrusive and clamp on externally. As they are outside the flow, they cause insignificant head losses. Since they do not operate hydraulically and no mechanical parts are exposed to the fuel that have a potential to wear, seizure and choking of the fuel flow is very unlikely. Ultrasonic meters are sensitive and have practically zero response time. They are insensitive to pulsing flow, and remain accurate at small fractions of their rated capacity. Impurities and suspended gas bubbles will cause erroneous readings with ultrasonic meters.

Models researched have been found suited to pipe diameters as low as 10mm. However, even for these narrow pipes, the lowest fluid velocity ratings correspond to flow rates of 120 litres per hour. Devices such as these would be suitable only for the very largest diesel engines in the UK fleet.

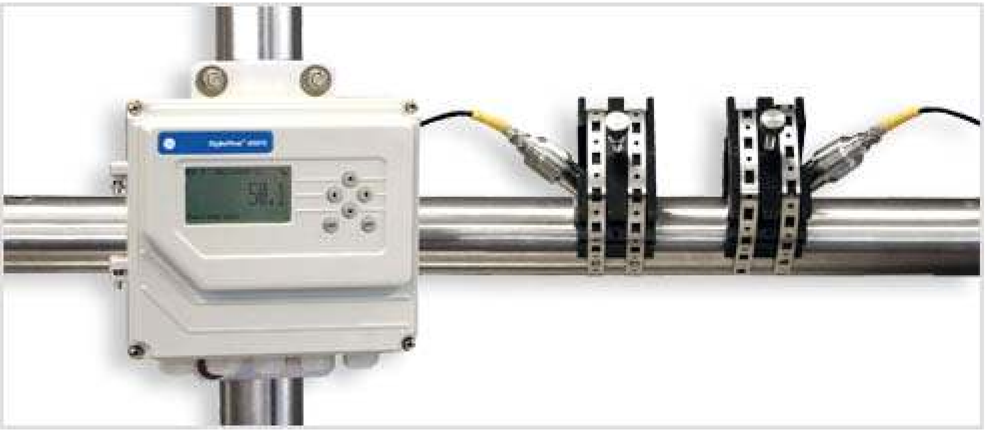

Figure 10: Panametrics ISX878 Intrinsically safe ultrasonic flow meter suited to diesel and other hydrocarbon flows.

Mass sensing flow meters

Coriolis meters

Unlike all of the meters previously listed, coriolis meters measure mass flow-rate instead of measuring or inferring volumetric flow-rate; this is a desirable characteristic as it eliminates the problem of varying thermodynamic properties between supply and recovery fluid lines. Additionally, unlike volumetric meters, mass-flow meters are insensitive to gases suspended in the fluid. Some manufacturers indicate that pressure drops across these devices can be appreciable and greater than the head provided by the lift pump in the fuel delivery system. In this case this may prove an inhibiting constraint on their use in fuel metering applications. However, other manufacturers quote device pressure drops that are lower and in this instance Coriolis meters would be ideal (but for cost!). The pressure drop aspect of these meters will continue to be the subject of investigation.

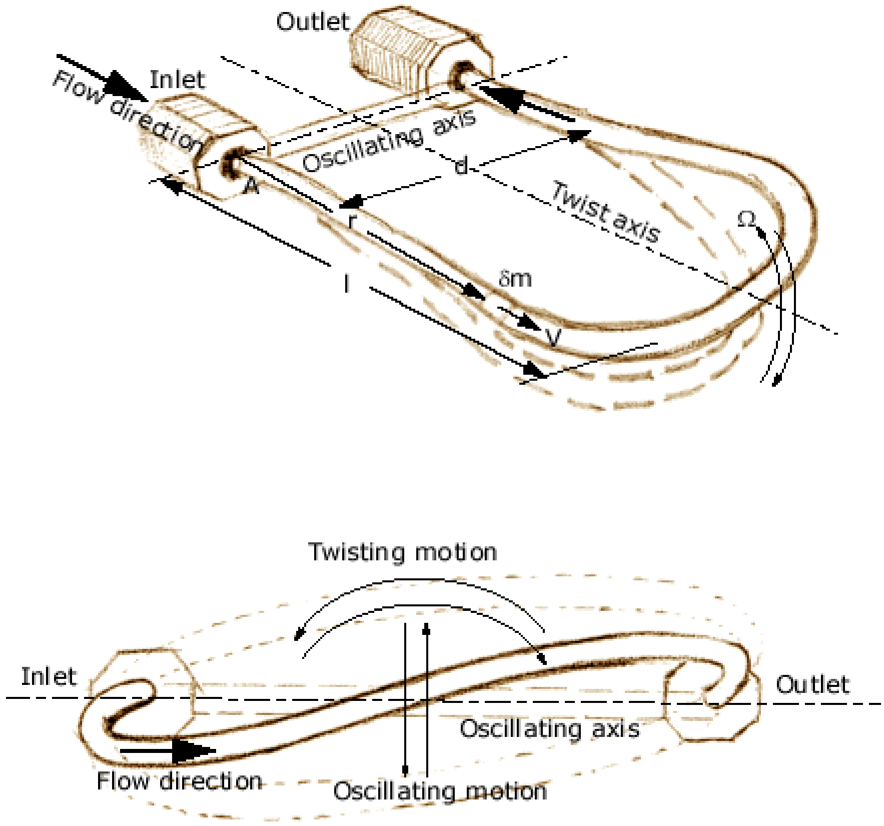

Figure 11: Principle of operation of a Coriolis mass flow meter. Amplitudes of twist and vibration greatly exaggerated for illustrative purposes. (Source: www.efunda.com)

The flow is guided into the U-shaped tube. When an oscillating excitation force is applied to the tube causing it to vibrate, the fluid flowing through the tube will induce a rotation or twist to the tube because the Coriolis acceleration acts in opposite directions on either side of the tube. Frequently, two U-shaped tubes are driven in a counter-vibrating fashion to make the device less sensitive to external vibrations. When no fluid flow is present, the two tubes vibrate parallel to one another without twisting. With mass flow, the tubes vibrate with twisting causing a phase difference in measured displacement of each limb of the meter, the magnitude of which, is proportional to the mass flow rate.

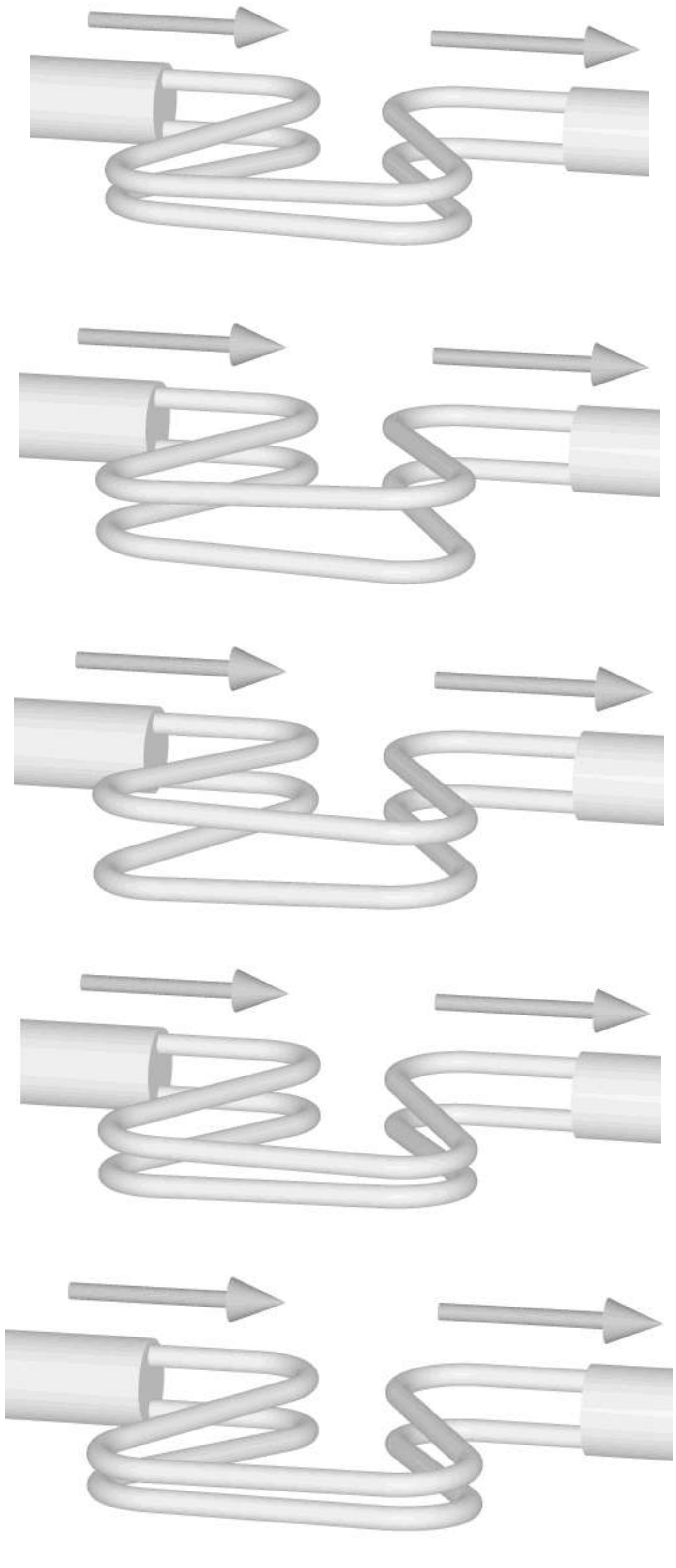

Figure 12: Illustration of motion of a two tube Coriolis flow meter when a fluid is flowing through the device.
(Animation at: http://commons.wikimedia.org/wiki/Image:Coriolis_meter_vibrating_flow_512x512.gif)

Linear Mass Flowmeters

The linear mass flowmeter is, in principle, a hydraulic equivalent of the electrical Wheatstone bridge. Four matched orifices make up the bridge and an integral constant flow recirculating pump establishes the internal reference flow. Sensing imbalance generated by external flow through the meter, the hydraulic bridge produces an output of differential pressure that is both linear and proportional to the true mass liquid flow. This flow meter has wide rangeability and is unaffected by changes in process temperature, density and viscosity. It is a fast responding flow meter that can detect very low flows at very low pressure drops. This meter is widely used in the automotive industry and wherever fuel systems are checked, such as in the manufacturing of fuel injectors. (Baker, R.C., 2002. An Introductory Guide to Flow Measurement. John Wiley ISBN 1860583482).

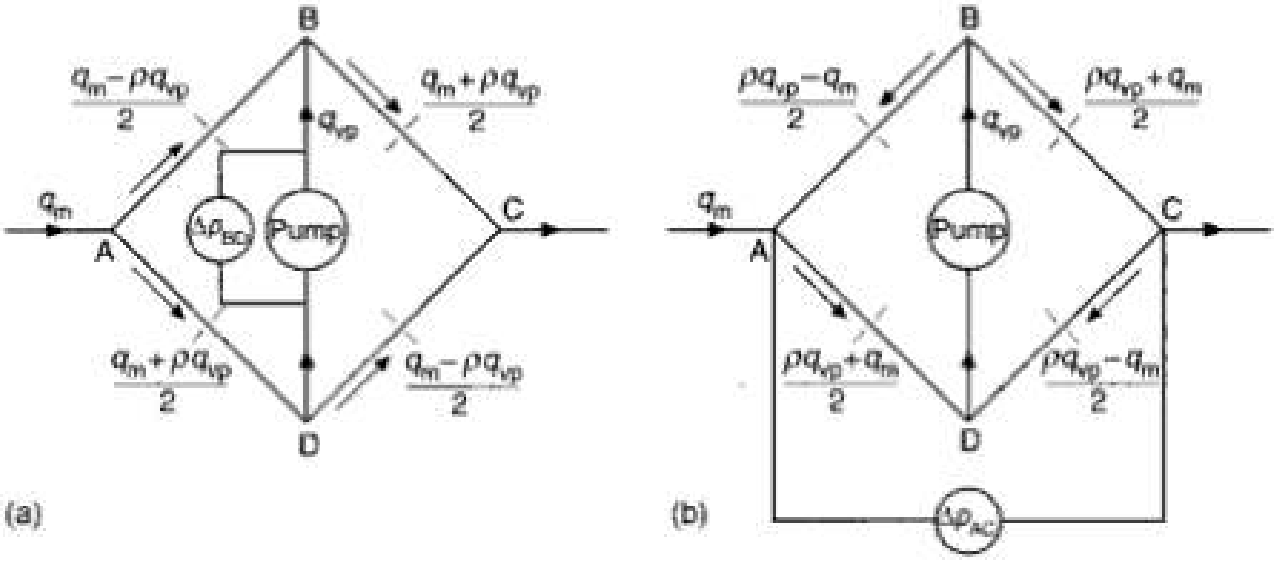

Figure 13: Hydraulic wheatstone bridge mass flow meter bridge flow circuits

For high flows: $q_m = \dfrac{\Delta p_{BD}}{K q_{vp}}$

For low flows: $q_m = \dfrac{\Delta p_{AC}}{K q_{vp}}$

where K is a calibration constant.

Figure 14: AVL FT10 hydraulic wheatstone bridge mass flowmeters. (Source: www.avl.com)

Thermal mass flow meters

These sensors are based on an operational principle that states that the rate of heat absorbed by a flow stream is directly proportional to its mass flow. As molecules of a moving fluid come into contact with a heat source, they absorb heat and thereby cool the source. At increased flow rates, more molecules come into contact with the heat source, absorbing even more heat. The amount of heat dissipated from the heat source in this manner is proportional to the number of molecules of a particular fluid (its mass), the thermal characteristics of the fluid, and its flow characteristics. (www.crossinstrumentation.com). Three main variations of thermal mass flow meters exist. Those that are based on differential temperature observations provide true mass flow observations as they 'see' the same pressure and temperature dependent fluid properties. In this sector of the flow metering market, there are far more sensors available for gaseous fluids than there are for liquids.

Figure 15: Brooks Instrument 5850 series MFC thermal mass flow meter.

Other device selection considerations

In addition to the above factors, some consideration was also given over to the testing conditions that the meters would ultimately be subjected to. A particular constraint was the FSD of a selected meter should match the range of expected flow rates for the marine diesel engine that is part of the CSM Diesel Engine Dynamometer Test Facility. Under maximum load at maximum rpm, fuel consumption of the test engine, which is nominally rated at 75 kW (100 hp), is around 6 g/s (21.6 kg/h). At idle the fuel consumption is around 2 g/s (7.2 kg/h).

The rating of the engine is at the low end of the spectrum of engine ratings that are installed in fishing vessels (Table 01). It is typical of the type of engine that would be installed in a 10m class potting boat. Thus, where there was a choice between manufacturers for a specific type of device, the device chosen was the one for which the manufacturer also provided models suited to much larger rates of fuel flow, using the same measurement principle and technology. The rationale supporting this is that the higher rated meters would be suited to larger trawler vessels.

Sensitivity to vibration through mountings and fuel line fittings was highlighted as a potential inhibiting factor for some of the measurement technologies in the shortlist. The six cylinder Perkins diesel engine that is part of the CSM Diesel Engine Dynamometer test facility can be expected to produce vibration at driving frequencies between 50 Hz and 125 Hz over its operating range of engine speeds. Any device with natural resonant frequency within this range may not perform well under testing. Many Coriolis meters are driven with frequencies of 80Hz. Discussions between the research team and Bronkhorst, suppliers of Coriolis meters, revealed instances of interference when frequencies of pair of adjacent Coriolis meter installations, were similar. The devices were sent back to the factory for detuning. Presumably, this means that if engine vibrations were interfering at the frequency at which a Coriolis meter operated, the meter could be reprogrammed to operate at a non-interfering driving frequency.

Key Points from Siddle (1984) study

SeaFISH Technical Report No. 239, "On-board Fuel Flowmeter Systems for Fishing Vessels", authored by W. Siddle in 1984 was supplied to the research team on Wednesday 30th July, 2008, after an earlier meeting to make preliminary decisions on the fuel meters selected for experimental trials in Phase 2 of this work. The key findings of the Siddle report are summarised below:

- The most cost effective fuel flow meter for a fishing vessel was a simple remote reading flow meter costing £1000 in 1984 (est. £1,750 in 2008).
- A positive displacement tranducer (oval meter) having a low pressure drop was the recommended meter.
- During trials with the selected meter, Siddle conducted in-service free running experiments on MFV ADAPTABLE where reducing speed from 8 to 7 knots led to fuel savings of 29%.
- A fuel meter installed on a vessel with a variable pitch propeller quickly leads to in-service determination of an optimal combination of pitch and engine rpm to minimise fuel flow during free running and during engine loading with fishing gear.

Siddle also provides very useful guidance on proper installation arrangements on fishing vessels, covering four different prevailing fuel delivery and return systems. Siddle recommends installation of a single sensor installation wherever possible. In the main this depends on engine manufacturer recommendations on return flow in the case when appreciable return flows exist by default. The research team are consulting with engine manufacturers in order to determine whether any 'rules-of-thumb' guidance can be established on:

- Engines that typically have appreciable return flows
- Whether or not the return line can be safely redirected into a tee into the feed line (Figure 18).

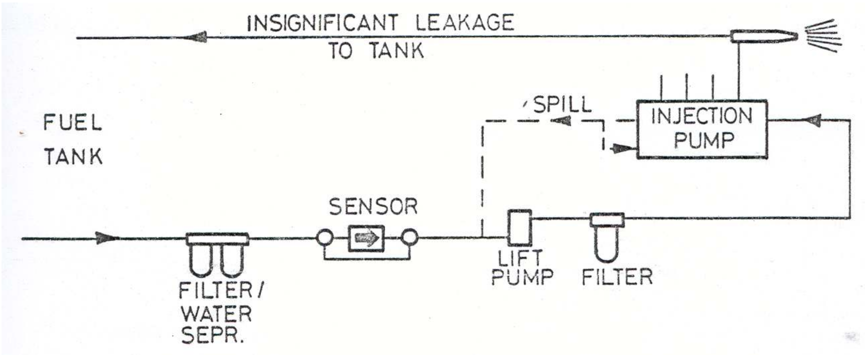

Figure 16: Single sensor fitted between filter and lift pump, before injection pump spillway return

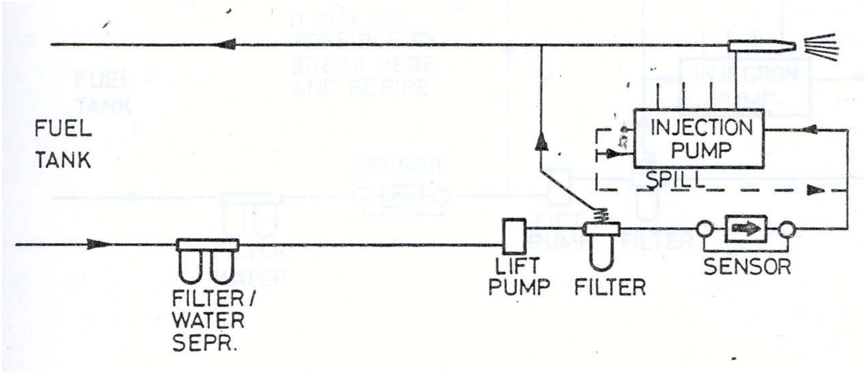

Figure 17: Single sensor fitted between filter and injector pump when engine has a relief spill to tank

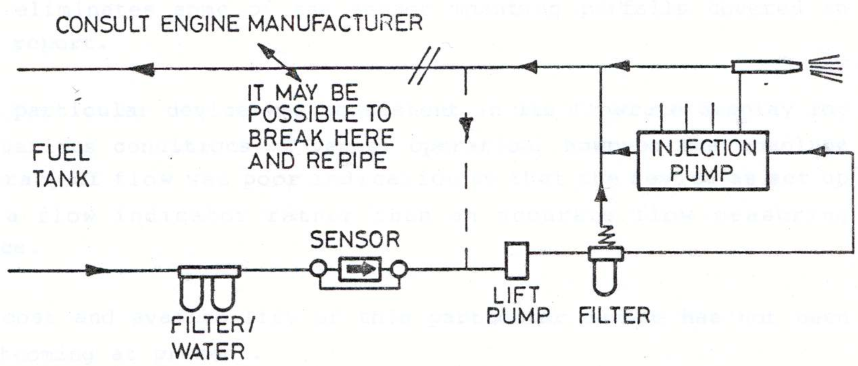

Figure 18: Single sensor used when engine has appreciable return flow to tank from filter relief, injection pump or injector spill (after consultation with manufacturer)

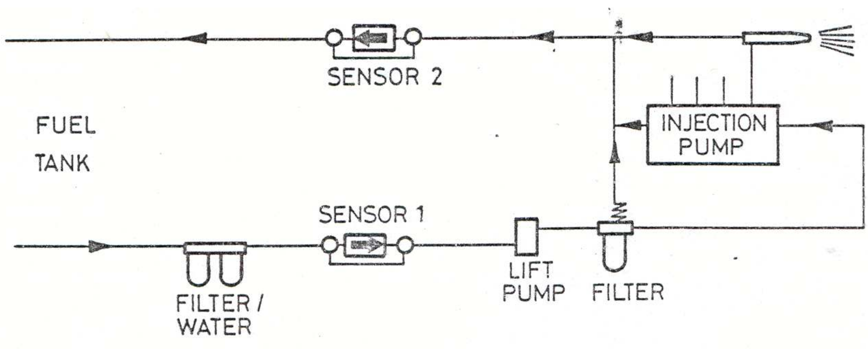

Figure 19: Two sensor installation set up for systems returning appreciable flow return to tank. Volume observations from sensors on return lines should be temperature corrected to temperatures of fuel in feed line for accurate net metering.

Table 02 : List of ultrasonic, pressure differential and true mass flow meters, suitable for fuel, considered.

Product	Manufacturer	Found at	Type	Min flow rate (l/hr)	Max flow rate (l/hr)	Accuracy	Repeatability	Max pressure (bar)	Power Supply	Inputs and Outputs	Connection	User Interface	Entrained Air	Temperature Correction	Pulsing issue	Price (£)	Notes	Test: Yes/No
UF25P100 Ultrasonic flow meter	Cynergy3	RS online 510-9051	Ultrasonic	30	1500	3.00%	1.00%	15	7.5 - 26V DC	Input - DC supply. Output - pulsed open collector.	10mm internal bore, 3/8" thread BSP	None (pulse or analog output)	"unaffected by fluid contaminants"	"Automatic temperature and viscosity compensation"	"Response time better than 0.4s" - will be unable to resolve pulses, no transients issue.	£150.00	Cheap, ready-made ultrasonic, in-line flowmeter. Gives 1000 pulses/litre. Linearity 1% of full scale.	No
DUL	Kobold	Globalspec	Ultrasonic	0	20m/s	0.50%	0.20%	Model dependent	24V DC	Input - DC Supply, pressure (4-20mA), temperature (4-20mA). Output - Pulse	Model dependent	None (Pulse output)	If < 2%	Temperature input	No transients.	Awaiting quote	Very large system, high current.	No
Product	**Manufacturer**	**Found at**	**Type**	**Min flow rate (l/hr)**	**Max flow rate (l/hr)**	**Accuracy**	**Repeatability**	**Max pressure (bar)**	**Power Supply**	**Inputs and Outputs**	**Connection**	**User Interface**	**Entrained Air**	**Temperature Correction**	**Pulsing issue**	**Price (£)**	**Notes**	**Test: Yes/No**
RCD	Kobold	Globalspec	Venturi	30	312	3.00%	1.00%	40	24 V DC +- 20%	Input - DC supply. Output - 4 - 20mA analogue output.	Model dependent	None	-	Only through calibration	Mechanical differential pressure device - possible transients.	Awaiting quote	Much wider range of flows catered for. However, 300mBar pressure drop unsustainable.	No
Product	**Manufacturer**	**Found at**	**Type**	**Min flow rate (kg/hr)**	**Max flow rate (kg/hr)**	**Accuracy**	**Repeatability**	**Max pressure (bar)**	**Power Supply**	**Inputs and Outputs**	**Connection**	**User Interface**	**Entrained Air**	**Temperature Correction**	**Pulsing issue**	**Price (£)**	**Notes**	**Test: Yes/No**
Cori-Flow	Bronkhorst		Coriolis	10	500	0.50%		5	15-24V DC	Input – DC supply. Output – 4 – 20mA sourcing.	1/2" OD compression	Optional Display.	-	Yes	N/A	£3,578	8 weeks lead time.	Yes
R Series	Emerson		Coriolis	0	8160	0.50%	0.25%	103	?	Input – DC Supply. Output - "Model 1700 transmitter"	Model dependent.	None	-	Yes	N/A	£3,000		No
Mass 2100 series	Siemens	Siemens	Coriolis	0	250	0.10%	-	230	24V DC	Through support kit.	1/8"	Mass 6000 kit	Mass flow meter – non-issue.	Yes	N/A	From £3117 for one transducer.	Very accurate, full system cost likely over £10000, used on automotive testing.	No
Liqui Flow L30	Bronkhurst	Bronkhurst	Themal mass flow	0.4	20	1.00%	0.20%	100 bar	24V DC	Input DC supply Output 4-20 mA	1/4"	?	Mass flow meter – non-issue.	Yes		Awaiting quote	This model is at upper range of test engine flow rate. Possibly not very responsive.	Yes
FT 10C	AVL	AVL	Hydraulic Wheatstone Bridge	0.045	136.078	0.5 % Reading + 0.01 % Range + 0.00045	0.25 % Reading + 0.01 % Range + 0.00045	13.79	240 VAC / 50 - 60 Hz	Output 4 to 20 mA	? For fuel systems testing	?	Mass flow meter – non-issue.	Yes	N/A	Awaiting quote	Unusual device, requires mains power, physically large.	No

Table 03: Positive displacement flow meters, suitable for fuel, considered

Product	Manufacturer	Found at	Type	Min flow rate (l/hr)	Max flow rate (l/hr)	Accuracy	Repeatability	Max pressure (bar)	Power Supply	Inputs and Outputs	Connection	User Interface	Entrained Air	Temperature Correction	Pulsing issue	Price (£)	Notes	Test: Yes/No
316s/steel oval gear flowmeter	?	RS online 447-4427	Oval Gear	0.6	66	0.50%	0.05%	50	5 - 24V DC	Input - DC supply. Output - high resolution pulse.	1/4BSP	None (Pulse output)	-	None noted	Positive discharge meter - should not be an issue.	£225.33	Two sizes (up to 240 l/hr)	No
M2	Macnaught	bellflowsystems.co.uk – M2ASP-1	Oval Gear	15	500	1.00%	0.03%	5	?	Input – DC Supply. Output – Pulse.	1/4" BSP female	MR100 LCD display.	-	None noted	Positive discharge meter – should not be an issue.	£275.80		Yes
Flowmate Oval M-III	Flowtech	icenta.co.uk	Oval Gear flowmeter	3	100	1.00%	-	98	5-45V DC	Input - DC Supply. Output – pulsed open collector.	RP 1/8" Female	None (Pulse output)	-	None noted.	Positive discharge meter – should not be an issue.	£210.00	Larger sizes available, up to 500l/hr. Economic total system (display ~ £280)	Yes
OG3	Titan Enterprises ltd	Gus docs	Oval gear flowmeter	3	600	0.50%	0.10%	400	? (Internal voltage regulator)	Input - DC supply. Output - pulsed open collector.	1/2" BSP Female	None (Pulse output)	-	None noted	Positive discharge meter - should not be an issue.	£243.00	May be not inconsiderable pressure loss.	No
KRAL systems	Intercontrol ltd	Gus docs	Spindle positive displacement.	18	1800	0.10%	-	40	?	Input - DC supply. Output - pulse from HE sensor.	G 3/4" Female	Advanced differential flow computer	-	Provided by flowcomputer.	Reversible positive displacement with reverse flow sensors - fully compensated.	£5,633	V expensive, but has reverse flow sensors and touch screen interface. Promises incredible precision - but OMC tranducers may not be necessary - use OME economy for fishing vessels.	?
OME series	KRAL	kral.at	Spindle p.d.	6	900	0.10%	-	40	?	Input – DC Supply. Output – Pulse.	Various	None (Pulse output)	-	Provided by flowcomputer.	Option for reverse flow sensors.	Awaiting quote.		Yes

Table 04: Turbine flow meters, suitable for fuel, considered

Product	Manufacturer	Found at	Type	Min flow rate (l/hr)	Max flow rate (l/hr)	Accuracy	Repeatability	Max pressure (bar)	Power Supply	Inputs and Outputs	Connection	User Interface	Entrained Air	Temperature Correction	Pulsing issue	Price (£)	Notes	Test: Yes/No
FT210	Gems Sensors	RS online 616-2693	Turbine (Hall effect)	6	150	3.00%	0.50%	25	5 - 24V DC	Input - DC supply. Output - NPN sinking open collector.	G 1/4" or ¼ NPT Male	None (Pulse output)	-	None noted	Turbine meter - may be an issue.	£32.00	Flow rate may be insufficient for large engines.	No
Series 65000 cruisemaster	Floscan	floscan.com	Turbine "opto-electronic"	1	180	?	?	?	?V DC	Input – DC Supply. Output – Pulse.	1/4"	Analogue dial with fuel totaliser.	Is quite severely compromised	Manual calibration.	Kit contains pulse suppressors.	£900.00	Price for 270hp engine	Yes
1/2" mini turbine	Titan Enterprises ltd	flowmeters.co.uk	Turbine	30	390	0.50%	0.10%	01/10/15	7.5 - 24V DC	Input - DC supply. Output - pulsed open collector.	1/2" BSP Female	None (Pulse output)	-	None noted	Turbine meter - may be an issue.	Awaiting quote	Low viscosity fluid. Flow rate may be insufficient for large engines.	No
Dataflow compact	Parker	RS online 185-9982	Twin-vaned turbine with phototransistor	60	1500	2.00%	1.00%	20	5V DC	Input - DC supply. Output - pulsed open collector.	3/8 BSP	None (Pulse output)	-	None noted	Turbine meter - may be an issue.	£38.62	Consult Parker Filtration on liquid suitability. RS puts accuracy at 5%, not 2% in datasheet.	Yes
LMSPFA.05	Litre Meter	litremeter.com	Pelton wheel	1.2	78	?	?	40	?V DC	Input – DC Supply. Output – Pulse.	1/4" BSP male	Head mounted display unit with linearisation.	-	Manual calibration.	Turbine meter - may be an issue.	£517.00	Other flow ranges available, this one is too low for testing.	No
Fluid flow sensor, 5 ranges	?	RS online 508-2704	Paddle wheel	3	30	2.00%	0.25%	10	4.5 - 24V DC	Input - DC supply. Output - Open collector.	8 or 12mm dia hose	None (Pulse output) Compatible with Kubler codix 544	Device should be mounted vertically if any vapour likely to form.	None noted	Turbine meter - may be an issue.	£81.30	Full range (up to 1.2 - 60 l/hr) requires changing out jet. Flow rate insufficient.	No
GFS10 NMEA 2000 fuel sensor	Garmin	mesltd.co.uk	?	7.6	190											£136.13	GASOLINE ONLY. Sends to Garmin chartplotter	No

Commercial flow meters selected for testing in Phase 2 of project

Tables 02 to 04 show flow meters that have been identified as potentially suitable for testing during Phase 2 of the project. The shortlist of devices to be procured is as follows:

- Bronkhurst Cori-Flow meter Coriolis meter (£3578, Loan in negotiation with manufacturer)
- Siemens Mass 2100 Coriolis meter (£3117, Loan in negotiation with manufacturer)
- Bronkhurst Liqui Flow L30 Thermal mass flow (Awaiting quote)
- Magnaught M2 Oval gear volume flow (£275.80)
- Flowrate Oval MIII Oval gear volume flow (£210.00)
- Parket DataFlow Compact Twin vane with phototransistor (£38.62)
- Floscan Series 65000 Turbine, opto-electronic (£900.00)

Undoubtedly, this list will change as work progresses with the project, but at this stage it is felt that this shortlist of devices reflect a good range of metering technologies. Siddle's recommendation is represented in the shortlist, but may not be the most suitable meter available, 24 years after his assessment was made, as the technology has moved on a great deal since that time.

CSM Simple flow metering concept

During the course of the Phase 1 desk study, discussions within the project team have resulted in an idea for an accurate and low cost real time flow meter for fishing vessels. The concept is based on the way that the governor of the diesel engine operates.

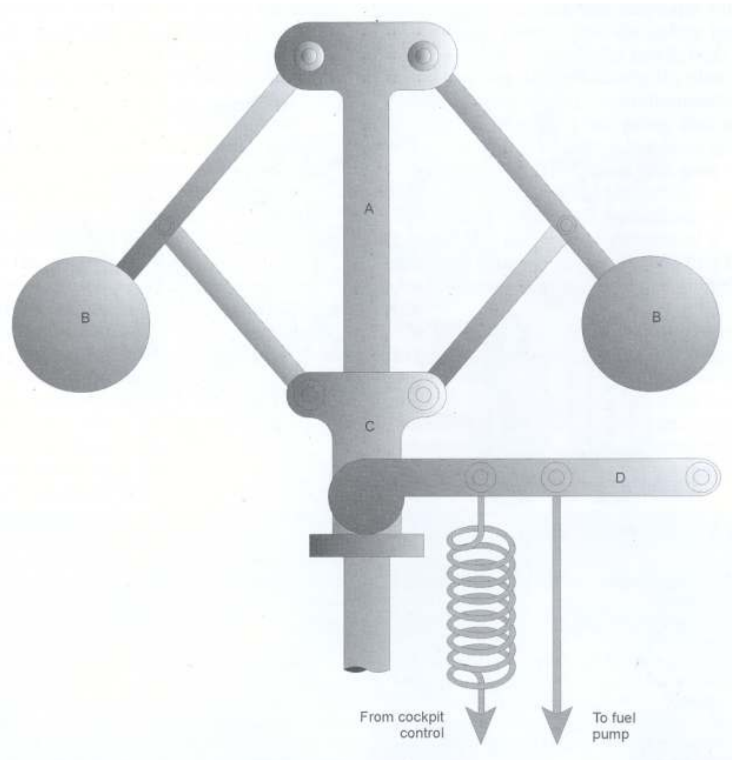

Figure 20: Mechanical governor of a diesel engine. (Source: RYA Book of Diesel Engines)

Speed control function of governor

Shaft (A) is driven off the engine crankshaft, so as the engine speed increases (say due to a reduction in engine load while traversing down from crest to trough of a long period wave during free running), the weights (B) try to fly outward. As the weights fly outwards, so they tend to draw their collar (C), upon which the left hand end of linkage (D) rests, upward. This upward motion of the linkage is so arranged that the connection to the fuel pump rack is adjusted so that the less fuel is passed to the injectors / delivered by the injectors, which in turn slows the engine back down to a speed determined by the setting of the cockpit engine control lever. In the converse case of higher load, the engine speed would decrease and the weights (B) would tend to move inward, so lowering the collar (C), on which the linkage (D) rests. The lowering motion of the linkage is so arranged that the connection to the fuel pump rack is adjusted so that more fuel is passed to the injectors / delivered by the injectors, which in turn speeds the engine back up to a speed determined by the setting of the cockpit engine control lever.

Adjusting the required engine speed for more knots

When the cockpit control is pushed forwards, for higher engine speeds, the increased tension in the spring, causes collar (C) to lower, which adjusts the fuel pump rack to meter more fuel to the injectors. At the same time, the increased tension makes it more difficult for the flywheel weights to slow the engine down, so the engine speed ‘stays increased’. The force balance between the governor weights and the spring tension keeps the engine running at a constant speed, set by the cockpit control. When the load varies, the engine speed may dip or rise momentarily but will quickly be restored by the governor control mechanism explained above. The actual mechanical governor inside a diesel injection pump is more sophisticated than in Figure 20, but the principle is identical.

The tension in the spring is an analogue for the fuel consumption

From the point of view of the fuel metering concept a key point to note is that the tension in the spring connecting the cockpit control to the governor will i) remain at a constant value while the load on the engine remains steady (where the magnitude of the tension will effectively be defined by the operator’s setting for engine speed and hence vessel speed) ii) reduce momentarily in the event that the load on the engine increases and iii) increase momentarily in the event that the load on the engine decreases. The tension in the spring is thus directly (inversely) related to the position of the fuel pump rack via the linkage, which in turn meters, precisely and repeatably, the amount of fuel delivered to the engine cylinders by the injectors. Thus, a load cell installed in the cable connecting the spring to the cockpit control would produce a valuable indicator of real-time fuel consumption. If the load cell readings were calibrated against fuel consumption values obtained through the use of a temporarily installed meter, the load cell reading would provide a calibrated observation of fuel consumption. It is possible that the load cell could be installed in the cockpit area, close to the place were the indicator will need to be installed.

Summary

- While Coriolis technology meets all the criteria for the application – providing the vibrations from the engine either have no effect on the meter or it can be isolated – they are expensive and it may turn out that the cost is not justified; theoretical drawbacks with alternative, cheaper, technologies may prove to be either insignificant or avoidable through system design.
- Angular-momentum meters would seem the second choice, however, despite numerous published patents, there are very few commercially available, and we have not found any suited to our flow requirements.
- The one hydraulic wheatstone bridge mass flow meter with a suitable flow rating has been identified but is very bulky and requires mains power so has been deemed unsuitable for fishing vessels.
- Simple differential pressure and electromagnetic devices have been identified as unsuitable due to pulsing flows and conductivity incompatibility respectively.
- A spring returned variable aperture meter (rotameter) has not been identified – as yet. The search will continue.
- Flow ratings for ultrasonic devices in the range suited to the CSM dynamometer test engine have not been identified – as yet. The search will continue.
- Of the remaining meters, a thermal mass flow, 2 oval gear flow meters and 2 turbine meters will be evaluated in Phase-2.
- Earlier work has identified ideal arrangements for installation of flow meters in the fuel delivery and return lines. It has also confirmed that a single meter solution may be applicable in many cases – reducing cost for fishermen.
- There is a good chance that flow metering can be accurately and precisely measured indirectly by monitoring the tension in the connecting cable between the cockpit engine control lever and the engine governor. This concept will be investigated while testing on the commercially available flow meters is underway on the dynamometer test engine.