PETROLEUM TECHNOLOGY SUPPORTS FISHERIES MANAGEMENT

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Abstract: No adequate technology has to our knowledge so far been developed for reliable online monitoring of harvested fish quantities. We demonstrate in this study that multiphase measurement technology successfully applied in the petroleum industry for measurements of pipeline flow of oil and gases (Nilsson, 1989; Stalheim, 1991; Halvorsen, 1992) also can be used for objective recording of withdrawals from the sea (Spilde, 2001). Our results show that the multiphase flow method represents a quantum leap with respect to quantitative measurement accuracy, reliability, and objectivity in fish catches measurement and reporting, compared to the conventional practice of manual level measurement (Røttingen et al., 2002) within the on-board fish tanks. We conclude that modern resource management by adopting this technology can be taken to a new level through objective, online monitoring, substantially reducing uncertainties and unknown factors.

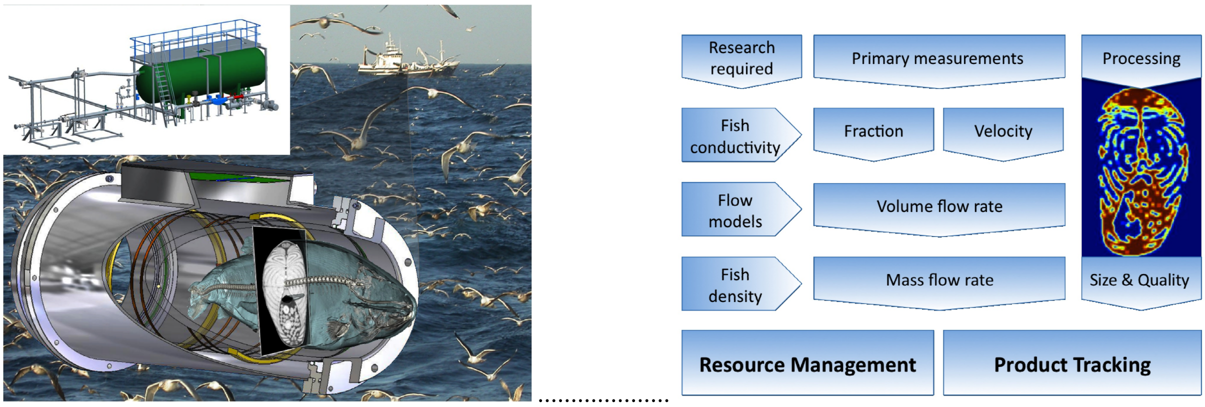

Figure 1:
LEFT. The fish flow meter (FFM). Top left corner: The CMR Multiphase Flow Loop, which is used to calibrate the multiphase flow meters for the petroleum industry. The main picture shows a purse seiner and a drawing of the FFM with an outline of the electrode arrangement. An electrical field is established within the sensor measurement volume, and the amount of fish in the pipe and its velocity through the pipe is determined from resistivity variations due to sea water and fish having different resistivities. From CT and MR imaging we can extract structural properties of fish for use in our measurement models. The illustration shows a CT image of Atlantic salmon depicted using VolumeShop (http://www.volumeshop.org)

RIGHT. FFM development. The left column shows the research tasks required since 1996, the middle column shows the calculations for biomass estimate based on the results from the required research. The right column shows a Matlab analysis of an image of fat distribution (Dixon) from MR images; red colour indicates fat content of 100% in a 5x5 pixel frame while blue colour indicate fat content below 5 %. The significance of studying the fat contents is shown in the seasonal variation in the FFM measurements (Fig. 3d), and is of special significance for further studies on product quality and traceability.

1 Introduction

The development of a fish flow meter (FFM; Fig. 1 *LEFT*) for the purse seine fisheries started in 1996 within the multiphase metering technology environment in Bergen, Norway, at Christian Michelsen Research AS (CMR) and the University of Bergen (Nilsson, 1989; Stalheim, 1991; Halvorsen, 1992; Spilde, 2001). The goal was to develop a useful tool for both fishermen, providing them with the possibility of self measuring the weight of their catch as well as operational parameters in connection with the fish pumping operation, and management, providing secure on-line measurement of fish outtake from the sea. As the development progressed it became obvious that a direct transfer of technology and methods would not be adequate.

A multi-disciplinary approach was needed whereby structural and functional properties of fish were correlated with physical measurements (Fig. 1 *RIGHT*). Multiphase flow meters feature flow velocity measurement to allow calculation of the volume flow rate of typically two or three fluid phases of i.e. oil, gas, and water. The mass flow rate is obtained from volume flowrates by multiplication with the mass densities of the phases, and total mass is obtained by integration throughout the duration of the pumping process. In the case of for example a two-phase oil and gas flow measurement, absolute uncertainty of measurements is typically in the range of 2 to 5% for both phases depending on conditions, while fiscal measurements (buy and sale) of single phases (oil or gas) has an absolute uncertainty of 0.3 to 1.0%at all conditions (Thant et al., 2008). In the context of the present work the FFM can be characterized as fiscal with respect to its application and multiphase with respect to the measurement problem. The high precision obtained for multiphase flow meters in the petroleum industry is partly based on current knowledge of physical properties of these phases (i.e. density and electrical conductivity). For fish, however, such knowledge has so far not been available and had to be provided in course of the present research. This issue is further complicated by the fact that fish properties vary among species, and as a function of developmental stages, habitat and season (Brix et al., 2009a; Brix et al., 2009b). In this respect we have analyzed more than 200 fish for density measurements by the up-thrust method combined with electrical conductivity measurements, and 85 fish (herring, mackerel and salmon) for complete CT and MRI scans to reveal structural information including spatial distribution of fat (Fig. 1 *RIGHT*). These analyses have not only provided us with unique material for developing fish property models to optimize FFM measurements, but also with the material for the next generation development including features for product quality and traceability, which is strongly demanded by both fishermen and the quality demanding consumer.

2 Results

The FFM technology was tested for a period of four years onboard three Norwegian purse seiners at water flow rates in the range 0.3 and 10 m*s^{-1} with fish fractions between 30-85% giving fish flow rates of 50 to 2000 tonnes*hr^{-1}, at water salinities above 25 ppt. The catch analyses were based on measurements of 93 catches with a total weight of about 46627 tonnes of fish (Fig. 2). The figure shows relative deviations from the belt scale (Fig. 3a) measurements in percent as a function of catch size for the four species. Air released in the FFM will be recorded as extra mass and will contribute significantly to the general uncertainty if not compensated for as in our algorithms. However, in the case of fish with open swim bladders a significant amount of the air is already expelled due to compression in the seine/trawl in contrast to fishes with closed swim bladders such as cods (Gadiformes). Atlantic herring and capelin both have open swim bladders (physostome), while Atlantic horse mackerel have a large closed swim bladder (physoclist) with a large oval, and Atlantic mackerel have no swim bladder. Our structural analysis also revealed higher bone densities in the scombrids compared to herring and capelin(Brix et al., 2009a; Brix et al., 2009b). We believe that this feature in the combination with not having a swim bladder would increase the accuracy of measurements by the FFM. However, at present, sufficient data is not available to confirm this hypothesis.

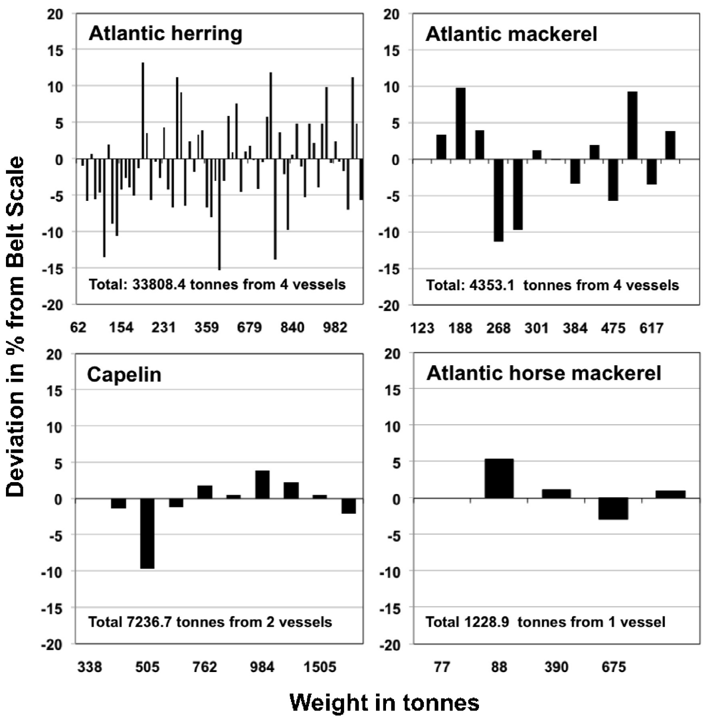

Figure 2:
Relative deviation of the FFM measurements in % of the reference value obtained from the belt scale for all 4 species. The catches are aligned starting with the smallest catches.

The statistics presented for the FFM are based on comparison of the FFM and belt scale measurements and thus contain uncertainties connected with both the reference - the belt scales used in the conventional method - and the meter itself (FFM). The prediction interval based on the data collected with the FFM and corresponding belt scale measurements (Fig. 2) was found to be 12% at 95% confidence level, which represents a 50% reduction in measurements uncertainty compared to the traditional way of measuring the catch at sea (Røttingen et al., 2002). Fig. 3c compares normal distributions based on statistics for the FFM and the traditional ways of measuring the catch (dipping the tanks).

Several physical, biological, and human factors mainly related to the transport and storage of fish between these two measurements also contribute significantly to the overall uncertainty observed in our data. The weight of the catch is measured on belt scales after the catch is pumped from the vessel to a fish processing plant. In some cases the catch is unloaded to vats or lorries for further transport to the processing plant. Such processes involve numerous manual operations and errors might occur resulting in inaccurate reports of catch weight. The measurement accuracy of the belt scale method is perceived as being 1% of the total weight of the measured catch. Verifying the uncertainty of this weighing method is very resource demanding and time consuming. On two occasions when we have carried out such in-depth verifications of the reference method, we have documented variations in the reference measurements of up to 6% during a days operation directly related to the belt scale weighing method. During this verification process of the reference method the water carry-over is compensated for, but in practical operations an unknown amount of water is following the fish over the belt scale. This is a well-known bias problem (not a random uncertainty), which may account for up to 2% of the total weight deviations. Furthermore the weight of individual fish may increase due to absorption of water by osmotic diffusion during transport and storage on board in water being hyposaline to the fish (Hjelm et al., 2006; Langmyhr and Otterhals, 2003). Thus, depending on the magnitude of this water uptake, the catch and landing statistics may be seriously biased. Special circumstances such as large proportions of eggs in spawning fish, particularly capelin, may contribute as much as 20-23% if the eggs are shed after being measured by the FFM but before landing as observed for three of our catches. Several other factors may contribute to the overall uncertainty, such as fish discard, erroneous use of the FFM i.e., but these are difficult to quantify. Seasonal variations in fish physiology (such as fat content) cause fish density and conductivity variations which also influence the FFM measurements of the fish as is shown in Fig. 3d for herring unless compensated for.

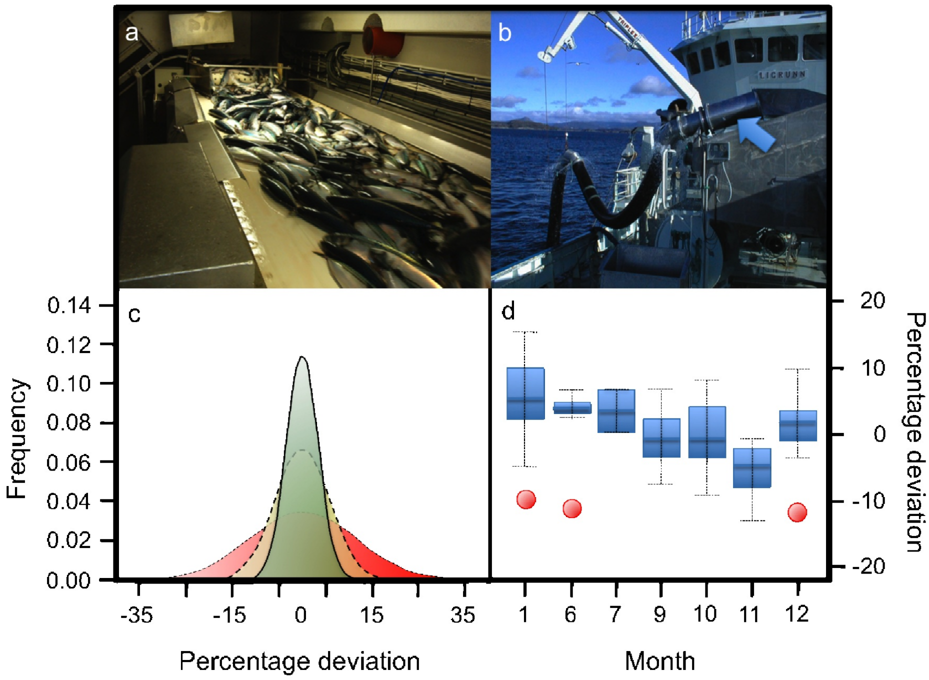

Figure 3:
FFM prototype testing. a, Picture of a belt scale. b, The 1st prototype (arrow) mounted on M/S Ligrun 1998-1999. c, Normal distributions based on statistics for the FFM (in yellow, 0 mean, 6% s. d.) from data presented in Fig. 2, the expected FFM distribution (in green, 0 mean, 3.5% s. d.), and the traditional method of measuring the size of catch (Røttingen et al., 2002) (in red, 0 mean, 12% s. d., data truncated at +/- 35%). d, Box-and-whisker plots of percentage deviation between FFM and belt scale measurements of herring catches in 2008 grouped by month. Three values are found to be outside 1.5 times the interquartile range (in January, February, and December).

3 Discussion and Conclusions

When developing new technology, the traceable reference methods used should have measurement uncertainties an order of magnitude better than the uncertainty of the technology being developed. But in this case the new technology has a much lower uncertainty with respect to measuring withdrawal from the sea than todays method of belt scale measurements, and hence an indirect way of establishing the uncertainty of the new technology is required. In this case the FFM uncertainty is documented by analysing a large statistical data set to find the total uncertainty of the FFM and the reference method when comparing measurements, and then backwards calculate the FFM uncertainty by estimating all the uncertainty contributions of the reference method. And in consideration of all the uncertainty contributions associated with the reference method in practise, and transport, storage and handling effects from the fishing fields to shore, the FFM uncertainty contribution to the total uncertainty shown in Fig. 3c has been determined as being in the order of 3.5% s.d. (Fig. 3c). This is indeed a quantum leap compared to the conventional method for fisheries management and recording of withdrawals from the sea.

In conclusion we have demonstrated that the FFM based on state of the art petroleum technology can provide modern resource management with objective and online monitoring, substantially reducing uncertainties of todays practices. Though the belt scale is relatively accurate with respect to measuring the landed fish, it is not suited for measuring the withdrawn biomass from the sea due to the number of uncertainties related to storage, transport and handling of the fish from catch to landing. We believe that the FFM technology has further potential for improvement through optimizing the measurement models; in particular those based on fish properties. Future development will focus on larger systems (i.e. 18”) implemented with traceability and quality measurement features compliant with the development of fishing gear that are optimized with regards to improved welfare and quality of the fish.

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.... APPENDIX...

Methods

The FFM technology is based on resistivity measurements as used in multiphase metering of water-oil mixtures where water is the dominating constituent (so-called water continuous flow). In the present application a mixture of seawater and fish is pumped through tubes and pipes from the sea into the fish tanks of a fishing vessel (Fig. 3b). The seawater is a continuous constituent of this flow, commonly called the continuous phase, while the fish constitutes a dispersed phase. The flow meter is built around a 14-diameter pipe spool integrated in the fishing vessels pipe system. The pipe spool is non-conductive, allowing the measurement instrument to set up electrical currents in the water-and-fish-filled measurement volume within the spool. The electrical potential drop across this measurement volume is measured and converted to a total volume resistivity. The resistivity of the seawater phase is monitored separately. Given sufficiently accurate knowledge of the resistivity of the fish, these measurement results can be combined to fish fraction, i.e., the volume proportion of fish in the pump flow, and the fish flow rate is obtained by combining this fish fraction with flow velocity and cross-sectional area.

Fish properties

In order to achieve proper resistivity and density models of the relevant fish species as a function of developmental stage and season we had to combine detailed structural analysis by CT and MR imaging combined with analysis by the up-thrust method and conductivity measurements for the same fish. Conductivity of the fish was obtained during the up-thrust measurement in a Perspex cylinder with a similar electrode configuration as in the FFM. The fish were thus sequentially imaged using a Light Speed Ultra CT (General Electric, Milwaukee, WI, USA) for estimating volumes and lengths of fish, bones and swim bladder, while a whole-body clinical 3 Tesla Signa Excite scanner (General Electric, Milwaukee, WI, USA), was used for estimates of fat and muscle volumes. A three-point Dixon imaging pulse sequence was then used to quantify the water and fat content in each imaged volume element (voxel) in the fish, while simultaneously compensating for inhomogeneities in the main magnetic field (Dixon, 1884). Regions of interests (ROIs) were defined for all images for volume determinations the nordicICE software (NordicImagingLab Inc, Bergen, Norway; 7) (Reeder et al., 2005; Reeder et al., 2007). The fat image data were re-sliced in an axial representation and averaged across 5 x 5 pixels for color coding and direct readout of the percentage of fat in the voxels using Matlab 7 (MathWorks Inc, MA, US).

Data analysis

Fish body and tissue weights were calculated from the estimated volumes and densities, which were obtained by the up-thrust method. The up-thrust experienced by a submerged object is dependent on the density difference between the object and the fluid (liquid or gas) that it is suspended in:

$$\rho_F = \frac{(m_W \rho_A - m_A \rho_W)}{m_W - m_A} \tag{1}$$

where $m_W = V\,(r_F - r_W)$, and V = the volume of the object, ρ_F = the density of the object, and ρ_W = the density of water (1000 kg/m^3).

The volume flow of fish through the FFM is estimated from fish fraction measurements. The area fraction (F) of the dispersed phase is estimated by:

$$F\,(\sigma_i) = \frac{\sigma_c - \sigma_t}{\sigma_c - \sigma_d} \tag{2}$$

where σ_t is the total measured conductivity in the measurement volume, σ_c and σ_d is the conductivity of the continuous and dispersed phase respectively. The volume flow rate (Q_d) of the dispersed flow component through a cross section (D) of a circular pipe is then given by:

$$Q_d = \frac{\pi D^2}{4} \nu F \tag{3}$$

where ν is the flow speed (m/s) estimated by cross-correlating the signals from the two ring electrode pairs in the FFM. The total transported mass through the pipe during time T can then be estimated by:

$$m = \int_T \frac{\pi D^2}{4} \nu F(t) \rho_d dt \tag{4}$$

where ρ_d is the mass density of the dispersed phase. In order to estimate biomass the FFM results needs to be scaled with species-specific correction factors. These factors are found from regression of FFM data and reference data.

The prediction-interval for FFM measurements, based on comparison with the belt scale, not knowing the standard deviation and the variance of the population, was calculated with 95% confidence from:

$$\pm t_{\frac{\alpha}{2}} s \sqrt{1 + \frac{1}{n}} \tag{5}$$

where s = standard deviation and t = student t value for a population of n, which implies that PI approaches 2*standard deviation when the data set increases.