On-line quality measurement of unhomogenized products with near infrared spectroscopy and neural networks

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Introduction

For the industrialized production of meat products for human consumption, such as hamburgers, patties, bolognas, sausages etc., the raw materials (mainly meat and fat) are standardized and mixed to an appropriate ratio according to a recipe. The mixing machines used in this process have a very high capacity, often from 800 to 1500 kg at a time. The raw materials for the mixing process are usually only coarsely ground and may consist of diced meat and fat with approximate dimensions $10 \times 10 \times 10$ mm. Until now manufacturers of these types of products have had to rely on at-line measurements for determining the fat, water and protein content of the mixed product. Here a sample (usually 1–3 kg) has to be drawn from the entire mixer load, then finely ground down to approximately 2 mm and homogenized carefully before being analyzed in, for example, an at-line near infrared (NIR) reflectance/transmittance instrument. This manual operation is time-consuming and also severe problems are encountered when attempting to draw a representative sample from the entire mixer load.

In 1994 one of the world's leading manufacturers of mixers for the meat industry, Wolfking Danmark A/S and the Danish Meat Research Institute decided to develop an NIR transmittance instrument that could be integrated with the company's existing mixing machines.

In order to get sufficient sample volume, the instrument should be able to measure through 4–6 cm of any meat/fat mixture with a high signal/noise ratio. Measuring time should be less than 0.5 seconds. It was also a requirement that a global calibration encompassing the most commonly used recipes could be made to give *RMSEP* values for fat measurements on fully homogenized meat samples better than 0.5% absolute when working in the range from 0–50% fat. The NIR transmittance instrument for this application must be robust towards extreme electromagnetic interference, mechanical chock and be easy to clean. The NIR transmittance instrument which has been developed and tested on meat products is now being launched under the name CFA (**C**ontinuous **F**at **A**nalyzer). In the near future, the instrument will be tested on a range of products such as cereals and livestock feed.

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The philosophy behind the CFA instrument

On unhomogenized products such as diced meat in a mixer, it is necessary to perform measurements on a very large sub-sample of the entire batch in order to estimate the true composition of the mixer content. In the preliminary design phase of the CFA development, a number of Monte Carlo calculations were performed to help decide how many sub-samples had to be measured by the instrument in order to determine the true composition of the entire mixer load as an average of single measurements performed on a multitude of sub-samples.

The inputs for this Monte Carlo programme were:

- The desired accuracy determined as the *RMSEP* (on the total mixer load).
- The known accuracy achieved on global calibrations (1–60% fat) on at-line or laboratory NIR transmittance instruments on fully homogenized meat.
- The approximate distribution in size of the meat/fat "particles" in the mixer, determined by the grinding conditions of the raw materials.
- The average fat content in the whole mixer load.
- The standard deviation for the fat distribution in individual "particles".
- An estimate of the sample volume from which light from the monochromator hits the detector.

The output from the programme is an estimate of the *RMSEP* between individual NIR transmittance measurements and the analytical content of each sample. The Monte Carlo simulations were based on the assumption that all distributions were either Gaussian or Poisson.

The simulations indicated that for sample volumes of about 100 cm^3 the most coarsely ground products (e.g. $13 \times 13 \times 13$ mm worst case) would have to be sampled roughly 15 times in order to get an *RMSEC* of around 0.5% fat for the entire mixer load (more than 800 kg). As it does not pose any major problem to extract 15 to 20 samples from the mixer during the time it takes to homogenize the mixer load, it was decided to go ahead with the development.

The CFA instrument

In order to be of use as an on-line measuring system on mixer systems the CFA NIR transmittance instrument had to meet the following overall requirements:

- Sample volumes per measuring approx. 125 cm^3.
- Measuring time less than 0.5 seconds.
- New samples should be introduced to the NIR transmittance cuvette at a rate of 20 min^{-1}.
- A global calibration must be developed for measuring almost any meat/fat recipe to minimize the need for customized calibrations.

The large sample volume was achieved by using several new design features. First the instrument would have to be able to perform measurements through at least 40 mm closely packed meat or fat. Also, the detector was chosen to have an active area of 24 cm^3. Useful measurements with this instrument on relevant meat products should be able to record data in the region from 5–8 OD.

The instrument uses a 50 W halogen lamp. An elliptical reflector focuses the light on to the tip of a fiber optic cable which ends up at a filter wheel monochromator. The filters have been chosen to cover the wavelength region from 770 to 1040 nm.

The sample compartment is made up of a 6 cm round stainless steel tube commonly used in the dairy industry. Quartz windows enable light to pass through the sample pipe on to the detector. The detector and amplifier were designed specifically for the new NIR transmittance instrument. The amplifier is linear and the appropriate range is automatically selected among 14 ranges from nominal f.s.d. 50 nW to 25 mW by the data acquisition software. This corresponds to detector resolution from 12 pW to 6 μW.

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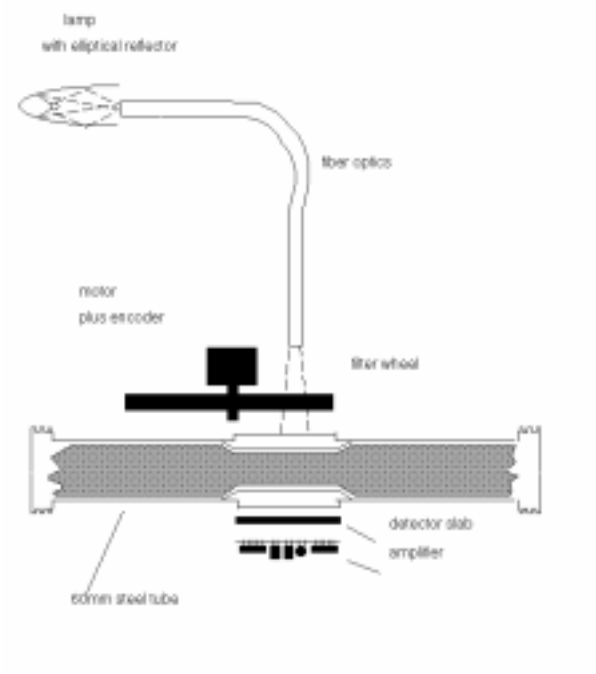

Figure 1. The CFA NIR transmittance instrument.

The instrument is schematically shown in Figure 1. A pneumatic pump is used for automatically drawing new samples into the measuring tube.

As the NIR transmittance instrument is to be used for processing of food for human consumption it has been necessary to create a system which is easily cleaned and disinfected. This has been achieved by placing the entire measuring device in a completely closed stainless steel casing. With this system the instrument can be dismantled from the mixer, placed in hot water for cleaning, reassembled and ready for new measurements—the whole operation is done in a few minutes.

All data acquisition for developing calibrations is performed on a master instrument. This means that a standardization procedure for slave instruments has had to be developed. For this the Danish Meat Research Institute has developed an algorithm for the CFA instrument which performs at the same level as the best known methods from the literature.[1,2]

Results

The NIR transmittance instrument is to be used for on-line measurements at many locations around the world. The meat processors who use the mixing systems from Wolfking Danmark need reliable calibrations that work on their standard products from day one of installation. To ensure that this is possible, a global and transferable calibration must be made. The Danish Meat Research Institute is using neural networks to accommodate the broad range in products that will go into the calibration. Experience has shown that artificial neural networks based on global calibrations give good results on NIR transmittance instruments on many food and feed products. The instrument is thus calibrated by a procedure which combines the data compression abilities of PCA/PLS with neural networks.[3–6]

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The predicted fat versus true fat for a large number of unhomogenized meat and fat samples are shown in Figure 2. Samples have been ground down to somewhere between 3 mm and 13 mm. The results shown in Figure 2 are single measurements on the unhomogenized product and, as can be expected, the *RMSEP* (2.2%) is rather high on account of the sampling error. It can also be seen from Figure 2 that many measurements have been made on the same volume of meat (2–3 kg in all). Each measurement corresponds to a sampling volume of roughly 125 cm^3. The reference measurements were made by grounding down and thoroughly mixing the whole portion (2–3 kg) and then finally analyzing a sample by ether extraction (soxhlet).

If, however, 14 measurements are made on the same sample and the predictions on the individual sample averaged, the result comes out as expected—the *RMSEP* and the R^2 are excellent, as predicted by the Monte Carlo program. This is demonstrated in Figure 3 in which the results of this averaging is shown for the same samples as presented in Figure 2. The *RMSEP* is here reduced to 0.41%, which is satisfactory considering the wide fat range (from 5 to 45%) of the samples.

The prime objective for developing the CFA NIR transmittance analyzer for the mixer systems is, that traditional at-line methods for assessing fat, water and protein in these large batches have not been able to meet the requirements for fast and reliable measurements. The introduction of the NIR transmittance instrument from Wolfking will enable manufactures of processed meat products to deliver products much closer to specifications than before.

Conclusion

A NIR transmittance instrument jointly developed by Wolfking Danmark A/S and the Danish Meat Research Institute has demonstrated that it is possible to make working calibrations on

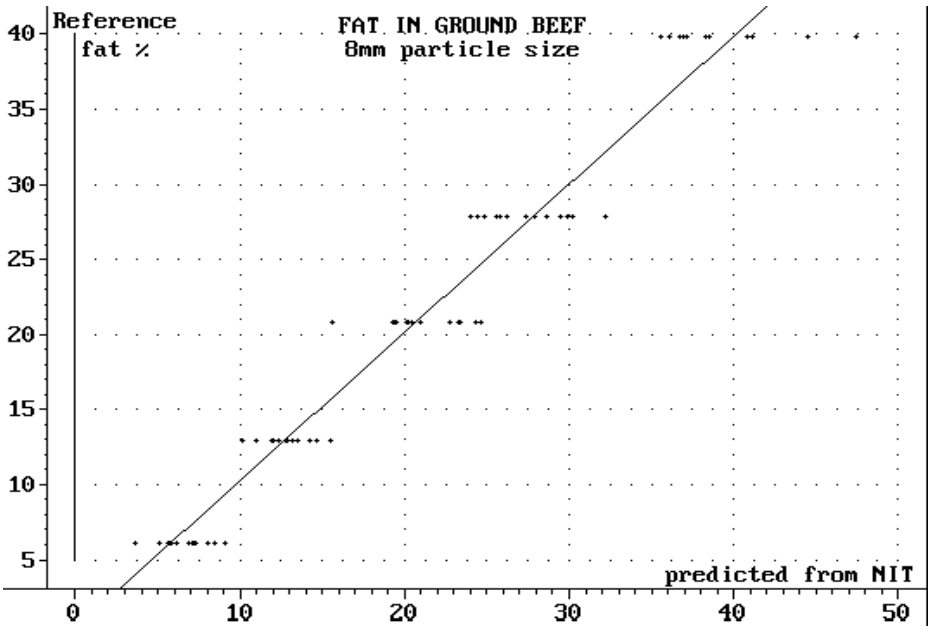

Figure 2: NIR transmittance predictions versus true for single measurements with the CFA instrument on unhomogenized ground beef samples with fat at five different levels.

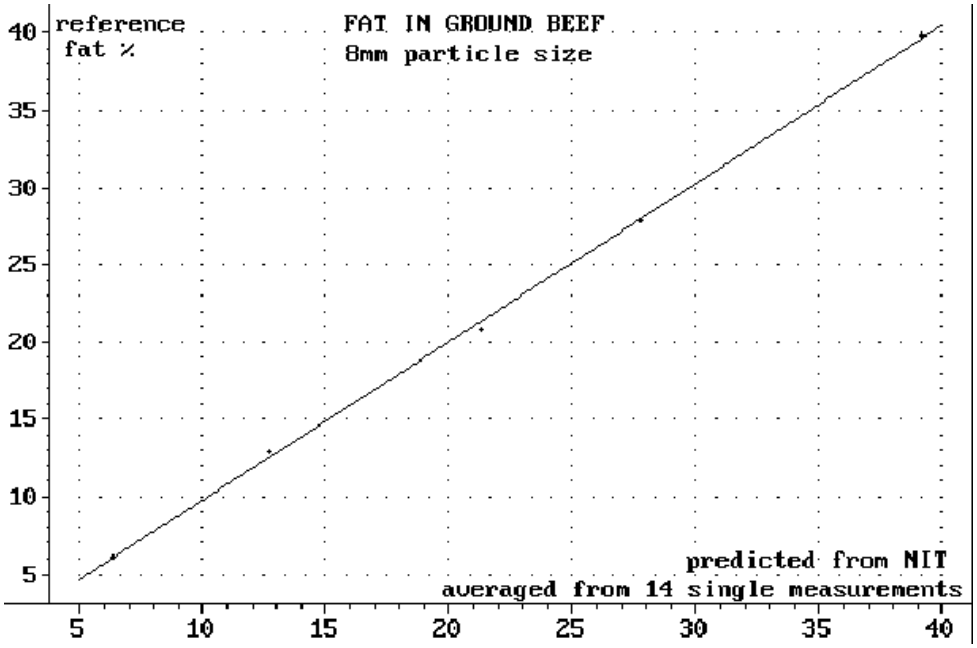

Figure 3: Predictions versus true fat in ground beef. Each point is the average of 14 single measurements.

unhomogenized meat products, and that this instrument enables accurate on-line determinations of fat, water and protein content in large batches in, for example, mixer systems.

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