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Meat lean measurement using VE microwave instruments

Initial trials at Cannon Hill CSIRO

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Executive summary

Fresh meat obtained from an abattoir located near Food Science in Brisbane was measured using two types of microwave instrument to characterise the ability to measure meat leanness. The two types of instrument configured as follows:

i) VE2 is a Pipe Sensor adapted to measure minced meat in a pipe; and

ii) VE4 is a Conveyor Sensor designed to measure product on a moving belt.

To make optimal use of the fresh meat samples, the meat was divided into several leanness grades and then reused in a series of experiments through preparation as large trims, cube cuts and then as mince.

The microwave data was compared against a series of leanness reference measurements obtained through standard lab techniques on extracted samples, one reference measurement per leanness grade.

Summary results show VE2 measuring mince in a pipe with standard error of 2.6%. Mince was hand packed in the pipe and the standard error includes the perturbing effects of varied packing density.

We believe that the VE2 Pipe Sensor system would provide a solution for approximately 0.5% CL error in situations where meat products can be pumped regularly through a pipe.

Conveyor results show VE4 measuring moving meat cubes with a standard error of 4.0% CL (Chemical Leanness) over a very wide range of leanness grades, and a standard error of 2.4% CL over a reduced leanness range of 75% to 90% CL. Measurement of stationary meat cubes over similarly reduced leanness range returned a **standard error of 1.3% CL**.

Analysis has allowed Keam Holdem to identify shortcomings in some aspects of the VE4 design, particularly the default over-belt configuration, which has added unwanted complexity to the data and contributed error to the results.

Continuing to take this technology closer to a real-world system requires reducing the two most significant sources of error, which we identify as the currently oversized microwave field area (the area of measurement) and the data complexities introduced by height variation, so an under belt system is proposed.

We believe that once these sources of error have been eliminated then the technique has the potential to yield a measurement accuracy of between 0.5 and 1.0% CL

Contents

1 Introduction

1.1 Microwave and Conveyor Equipment

The measurement technique employed by the VE2 and VE4 instruments uses a beam of low-powered radio waves directed at one surface of the meat product such that a pattern of reflections is created and measured to infer compositional properties. The technique is potentially very convenient for industry since only one surface of the meat needs to be aligned with the instrument, that surface can include a layer of protective cardboard or plastic packaging and the radio waves are inherently non-contact. Both VE2 and VE4 were developed for the dairy industry and were deployed in this trial without modification.

A conveyor belt fitted with a variable speed motor was added in the VE4 configuration to assist moving the meat samples with process-like regularity. For the relevant experiments the conveyor speed was set at a constant 25mm per second.

All measurements in these experiments were manually triggered, although an industry ready instrument would be modified to employ a form of automated triggering.

2 Experiments and Results

2.1 Fresh Meat Samples

Fresh meat trims were obtained from a commercial boning room pre-packaged in 27 kg cartons. The cartons had been manually packed to 60%, 75% and 85% CL specification. Optimal use of the fresh meat samples was made by dividing the meat into several leanness grades and then reusing these in a series of experiments through preparation as large trims, cube cuts and then finally as mince. The actual grades differed throughout the experimental sequence as fresh cartons of trimmings were obtained.

2.2 Independent References

After sorting and measuring each grade with VE2 or VE4, the grade was minced and a small sample extracted to determine the CL with an independent non-VE method. Estimates of CL for preliminary calibration purposes were obtained gravimetrically by drying samples at 103°C overnight and expressing the leanness by mathematical conversion of moisture content to CL % using a well known moisture-CL relationship. Subsequently, the dried samples were subjected to exhaustive solvent extraction to remove fat (AOAC Official Method 960.39). The CL% of each sample was calculated by subtracting the measured fat content (expressed as %) from 100

Table – Experimental Schedule

	Description
1	VE4, Stationary Conveyor 1" cubes, 3 grades, measurements to find height variation effects
2	VE4, Stationary Conveyor 1" cubes, measurements to characterise sample edge proximity effects
3	VE4, Stationary Conveyor Minced samples, 3 grades, 250 x 250mm bags, stationary conveyor
4	VE4, Stationary Conveyor Fresh meat trims, 7 grades, 250 x 250mm bags, 3 measured positions per grade
5	VE4, Stationary Conveyor 1" cubes, stationary conveyor, 5 grades, 250 x 250mm bags, 28 measured positions per grade
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12	VE2, Sensor Pipe Minced sample, 1 grade, measurements to find optimal minimum sample volume
13	VE2, Sensor Pipe Minced samples, 7 grades, hand packed in sensor pipe

2.3 VE4 - Height Variation Effects, Experiment 1

Purpose To find the best compromise between VE4-to-meat clearance and the measurement sensitivity of VE4 and define the optimal height range for use in the remaining experiments.

Method Fresh meat trims were sorted into three CL grades, cut to cubes of approximately 25mm size and bagged to retain moisture. Each grade was measured over a range of incrementally decreased clearances, using a hydraulic pallet lifter under the conveyor to vary the clearance. The conveyor belt was held stationary throughout.

Result Plotting the complex reflection coefficient at 1850MHz shows the VE4 optimally differentiates between the three grades at 55 mm clearance, but sensitivity remains good over clearances 65 mm to 40 mm and drops off gently outside this range.

This experiment 1 has found only a specific height clearance that optimises the instrument's sensitivity to leanness. A separate but related issue is the variations in height actually perturbing the leanness measurements, which is discussed further in the in the *Further Analysis and Conclusions* section.

2.4 VE4 – Edge Proximity Effects, Experiments 2, 7

Purpose To determine if meat samples measuring 350 mm x 350 mm in horizontal area are sufficiently large to ensure VE4 is measuring only meat and not any open conveyor area.

Method The intermediate CL graded bag was placed beneath the VE4 and measurements were taken. More bags of intermediate CL product were progressively added in the horizontal periphery of the test bag while looking for unwanted change in the microwave data.

Result VE4 is sensitive to proximity outside the 350 mm x 350 mm area, indicating that a larger sample size had to be used in all remaining experiments.

Experiment 7 extended this work by finding that a 500 mm x 450 mm area leaves 1.5 milli-Smiths of peripheral proximity sensitivity along each edge (this is equivalent to approximately 0.1 CL% error contribution from each edge), although the inner edge was found to be five times more sensitive making the total estimate for peripheral proximity error approximately 0.8%.

This means a sample of meat would measure approximately 0.8 CL% leaner if the sample's peripheral area was part of a larger area of product such as a long pile of meat trimmings. The inner edge exhibits greater sensitivity because of additional signal reflections from the legs of the instrument, suggesting that the meat sample's proximity to the legs of the instrument needs to be kept as constant as possible. This information should be incorporated in to a revised design of the system.

The reader should note that Experiments 3, 4 and 5 had been completed using small samples before analysis had found these sizes to be inadequate. Consequently, no further write up is made on experiments 3 and 4, although experiment 5 is retained because it used bags of intermediate CL product added in the horizontal periphery of the test bag to increase the apparent test area.

2.5 VE4 – Minimum Thickness Effects, Experiments 6, 11

Purpose To find the minimum thickness of meat sample required to obtain a repeatable VE4 measurement with a view to undertaking all following experiments using meat samples of at least the minimum found thickness.

Method Meat cubes from the fat CL grade were placed on a plastic tray. The tray was lifted 3 mm above the conveyor belt using plastic spacers, allowing a sheet of aluminium foil to be slid under the meat and tray. Measurements were made and the thickness of the meat cubes was progressively reduced until the presence of the aluminium foil could be seen perturbing the microwave reflection signals.

Result Meat thickness was reduced down to 70 mm. At this thickness the foil deflections accounted for approximately 2 milli-Smiths deflection (this is equivalent to approximately 0.13 CL% error.) Below in the *Further Analysis and Conclusions* section we model how the prediction error varies with meat thickness.

2.6 VE4 – Cubes on Stationary Conveyor, Experiment 5

Purpose A simplified experiment, intended only to measure sufficient meat grades for mathematical analysis tools to support a first time demonstration of the system and undertaken before the findings of experiments 2 and 7 were available.

Method Cubes of meat, sorted into five grades and placed in bags of area 250 mm x 250 mm, were measured. Measurements were made while meat was stationary in seven different positions, configured by manually pushing the meat forward approx 10 mm in the conveyor direction between taking each measurement. After a series of seven measurements the meat was returned to its initial position and the bag was opened and stirred. This series of incremental measurements was repeated four times for each CL grade.

Result Analysis of the data revealed that the bag area of 250 x 250 mm was inadequate. Despite the inadequate bag area we found by combining the microwave signals in a linear model, the data predicted the reference values with a standard error of just 1.3 CL%.

Below in the *Further Analysis and Conclusions* section we compare this data with the moving conveyor data to assess a source of error.

2.7 VE4 – Mince on Moving Conveyor, Experiment 8

Purpose To investigate the feasibility of an automated measurement triggering system that is based on signal recognition. Such a system is expected to recognise when meat is loaded under the VE4 by monitoring the microwave signals and triggering measurements automatically.

Method Minced meat was sorted into three grades and placed in bags of area 500 mm x 450 mm. The conveyor was run continuously at 25 mm per second and measurements were begun when the leading edge of the mince approached the VE4 sensor head, continuing until the mince was centred beneath the VE4. In all, a series of 10 measurements were taken. The series of measurements were repeated after rotating bag 180° on end.

Result Analysis focused on defining boundary conditions in the microwave signal data to infer meat position. Boundary conditions were applied to the complex reflection signals at frequency

1850MHz, however no one single boundary area could be found to accurately discern the meat position for all three meat grades examined.

This indicates that in a commercial installation, an external photoelectric eye or similar automated trigger should be used.

2.8 VE4 – Moving Conveyor Trims, Experiment 9

Purpose To develop a calibration model for demonstrating measurement accuracy on standard sized meat trimmings.

Method Fresh meat trims were sorted into four grades. Each pile was stacked on an uncovered plastic tray such that the meat area was 550 mm x 450 mm, and thickness 55 mm. The conveyor ran continuously at 25 mm per second and a series of measurements were taken, starting as the approaching trims were 30 mm before centre and measuring 10 times as the meat passed under the VE4 to finish 30 mm after centre. The trims were re-stacked after each pass.

Result Combining the microwave signals in a linear model predicted the reference values of the four CL grades with a standard error of 4.5%, an accuracy similar to the moving 1" meat cubes below, which is encouraging because it indicates sample presentation may not be as crucial as first thought. This would be useful in commercial applications where measurements on fresh trim without prior size reduction will be preferred.

When analysing this data it was found that measuring a wider CL % range comes at the expense of reduced measurement accuracy. A reduced CL range was investigated by removing the data for the fattest grade (47.5 CL) from the data set; this showed an improved standard error of 2.4 CL%, suggesting maximum accuracy required a practical range of CL% to be chosen, perhaps 30% CL between extremes. This means a calibration would have to be established in that range - as either high fat or high lean depending on where accuracy is seen as most valued for a given application. The VE4 could store multiple calibrations and easily switch between these.

2.9 VE4 – Moving Conveyor Cubes, Experiment 10

Purpose To develop a calibration model for comparing accuracy of moving meat measurements with previous stationary data.

Method The four grades of meat trims used in Experiment 9 were further prepared by cutting them to 25 mm cubes. Each grade was placed in bags with area 480mm x 350 mm, 70 mm thickness. It was possible to use smaller bag areas than for experiment 9 because the regularity of cubes permitted these bags to be formed with cleaner, well-defined edges. The conveyor was run and measurements made as per Experiment 9.

Result Combining the microwave signals in a linear model predicted the reference values with a standard error of 4.7%. Interestingly, when we applied a one-second moving average to the prediction the standard error improved to 3.71%, but the fact this improvement is quite modest suggests that remaining error is not random but rather systematic. On that issue we discuss more in the *Further Analysis and Conclusions* section.

2.10 VE2 – Pipe Loading Effects, Experiment 12

Purpose To determine if loading the VE2 pipe flush to its end caps supplies sufficient meat volume to make repeatable measurements.

Method An initial trial indicated that a stream of cubed meat could not be driven with a pneumatic plunger through the 100 mm diameter pipe because of the constriction caused by the sensor. For experiment 12, the VE2 pipe was filled with intermediate CL cubed meats by hand packing it. Measurements were taken, first with open ends and then with reflective metal end plates held over the ends of the pipe, looking for unwanted change in the microwave signals.

Result The metal end reflectors were not seen in the data, indicating the full pipe sample volume is sufficient and could be used in experiment 13.

2.11 VE2 – Pipe Measuring Mince, Experiment 13

Purpose To develop a calibration model for demonstrating measurement accuracy on mince product through a pipe.

Method Attempts were made at mechanically pushing the mince with the pneumatic plunger used in Experiment 12 but the pressures required led to expression of an excessive quantity of juice and variable product flow rate. Therefore we instead resorted to hand packing the pipe with mince and taking measurements with the mince stationary.

Meat was sorted into seven grades before mincing. Measurements were made in triplicate repeats, repacking the pipe between each measurement.

Result Combining the microwave signals in a linear model predicted the reference values with a standard error of 2.6%. Further comment is given in the *Further Analysis and Conclusions* section to follow.

3 Further Analysis and Conclusions

The experimental work has determined error levels for measurement of different meat types using un-optimised dairy instruments. Further analysis of the data identified which parts of the system are likely contributing error, making it possible to recommend necessary changes.

3.1 Pipe Sensor

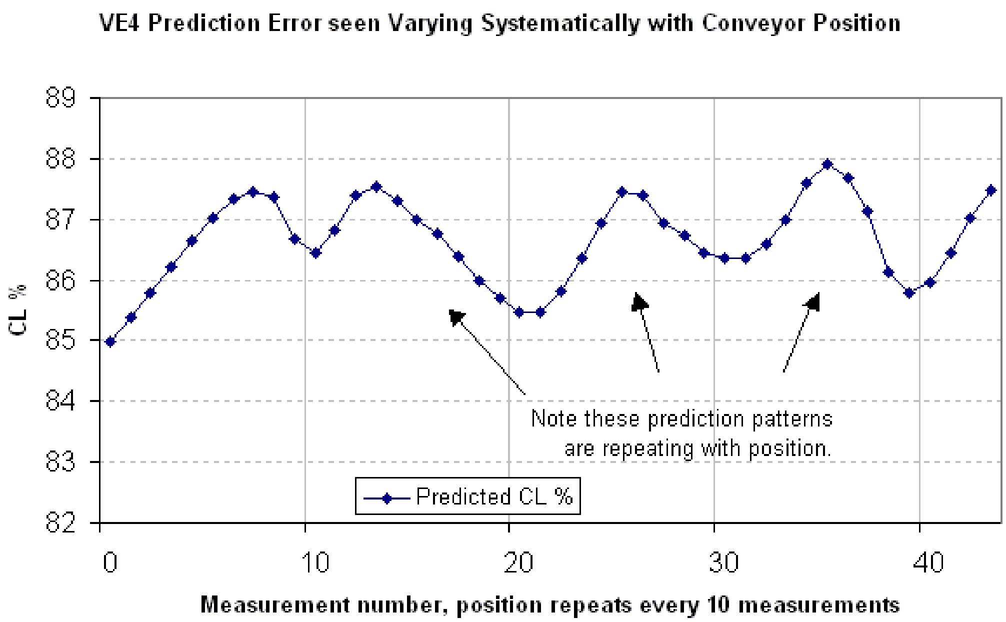
In this trial the meat had to be hand-packed in to the sensor pipe, although our dairy experience has shown the accuracy obtained with hand-packed product to be considerably worse than can be obtained for continuous pumping. In the butter industry (where product is continuous pumped through our sensors) we achieve accuracies from 0.1% to 0.3% compared with 2% for hand packed experiments. Provided the air is largely expelled in the grinding/pumping process we would expect further trials with continuously pumped mince to achieve similar relative improvements. This could also reasonably be expected for any pump-able meat products.

Further trialling would also prove the 4” pipe sensor is scalable to an 8” design for fit with commonly found pipe systems in processed meat factories.

3.2 Conveyor Sensor

Our analysis efforts in this series of trials focused on conveyor measuring meat as it moved along a conveyor due to a lack of currently available solutions for this application, which also makes it an ideal niche for development.

Stationary and moving conveyor experiments 5, 9 and 10 all make good predictions of the average CL% but individual measurements are seen to vary with position as shown in the following chart. This chart shows predictions of the 85.9 CL% grade meat trims in experiment 9, measured in ten repeated positions. The grey vertical marker lines show when the meat sample was returned to the first position and the same pattern of positions were used throughout the whole experiment.



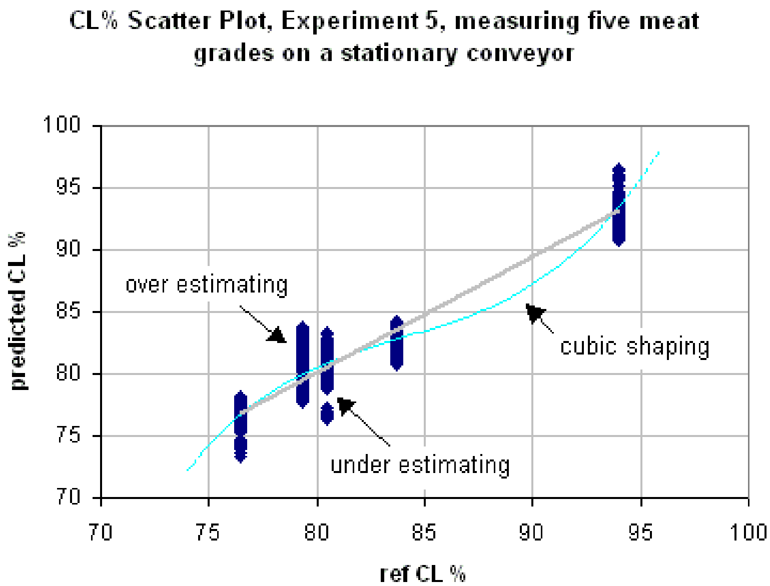
The above chart shows the predictions tending to follow a pattern repeating with position (rising as the centre of the sample gets closer to the centre of the VE4, and then reducing as it recedes away), but its error complexity cannot be routinely modelled from the experimental data. Furthermore, the positional dependence indicates the error is determined by physical features of the system such as height variation and sample size variation as discussed below.

Height variations can be managed by a compensation technique if the effects are reasonably linear, but in this situation they are not because height has a secondary effect of varying the reflections seen from the floor stand and conveyor sides. A solution is proposed below to reduce the clearance variations between the instrument and the meat.

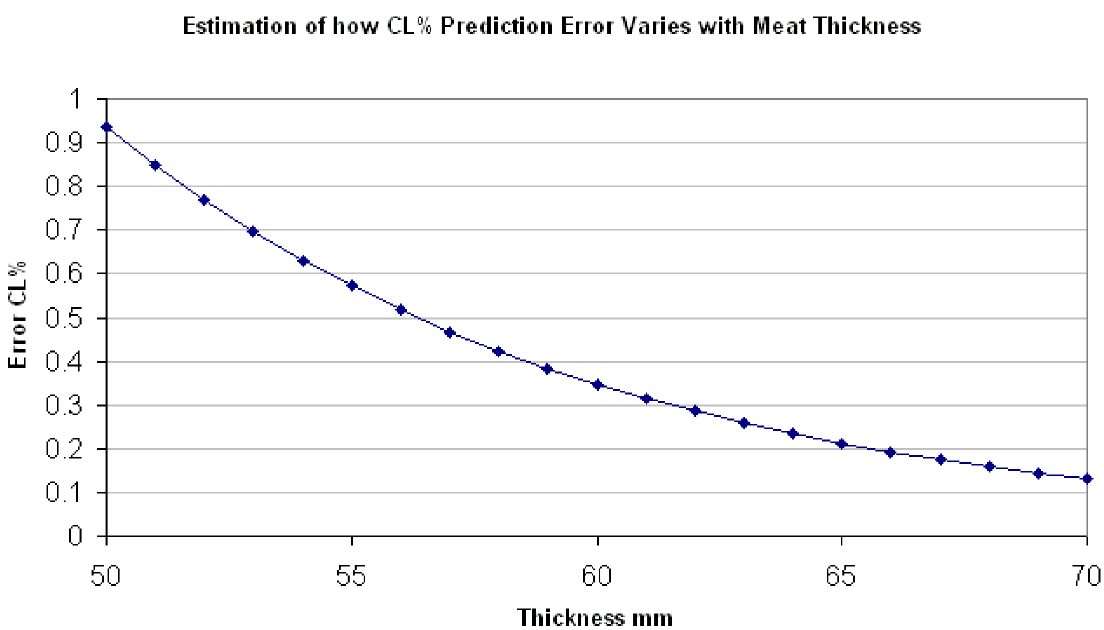
Sample size variations are significant in this series of trials because the meat samples used were always smaller than the total area captured by the reflected wave beneath the VE4 (as determined by experiments 2 and 7). The limited sample sizes are responsible for the positional errors described in the chart above. Rather than increase the sample sizes, which is assumed to be impractical for industry, experiments 2 and 7 show that we can instead limit this source of error by constraining the boundary edges of the sample. Solutions are proposed to reduce the variations in sample size and to reduce the total area captured by the reflected wave beneath the VE4.

Note the positional errors are confirmed as not introduced by conveyor motorisation (at the 25 mm per second conveyor speed used in these trials.) We compared raw reflection data between stationary and moving experiments, showing that very similar reflections for similar meat grades occurred in both experiments.

Throughout the post-trial analysis we have used only linear models to relate the microwave reflection signals to CL, because increasing the model complexity with extra (non-linear) terms would have required a far greater number of sample grades in each experiment to ensure a non-linear model would remain continuous. However, using a non-linear model would likely improve the accuracy, as the below scatter plot from experiment 5 shows that some soft cubic shaping is evident from our linear-only model:



Experiments 6 and 11 sought to find the minimum thickness of meat sample required to obtain repeatable VE4 measurements. From this we obtained a signal attenuation factor for meat, which has been extrapolated over a range of meat thicknesses to demonstrate how reflections from the back of the sample will contribute to the total CL error. The following chart shows our estimation for how meat sample thickness will contribute to the total CL error:



4 Suggested Path to Commercialisation

4.1 Height Variation

Height variation needs to be largely eliminated from the technique. We recommend reconfiguring the VE4 to measure through the conveyor from underneath. Conveyors made of standard engineering plastics polypropylene and PTFE are microwave transparent, do not absorb moisture and do not interfere with the reflection signals. Alternate materials like Acetal would need to be assessed for suitability given the above criteria.

Measuring from underneath the conveyor brings three related instrumentation advantages:

i) Height clearance variation becomes much reduced so more of the resolving power of the instrument is available for leanness modelling and less is consumed for error corrections calculations;

ii) Much less wave will escape from the vicinity of the antenna to be perturbed by the (highly variable) environment, which will reduce a significant source of random scatter in the reflection data; and

iii) Complex (non-plane wave) variations in reflection are largely eliminated from the signals, greatly improving the ability of our linear calibration models to associate reflection with leanness. These variations are dependent on both height and surface roughness, and so have been wasting considerable resolving power.

4.2 Measurement Area

The measurement area (the microwave to meat interface) is a compromise – too small and it inadequately samples the inherent variation of the product, but too large and it is perturbed by reflections from the edges of the product.

The area of reflection measurement is currently too large in that it includes the edges of the target meat region. It needs to be reduced to better match the volumes of meat we are typically testing. The internal antenna currently incorporated in VE4 defines the area of measurement, but using a microwave interface under the belt will allow the area of reflection measurement to be only slightly reduced for a large reduction in edge effect perturbations. This is because the wave attenuates much more per centimetre in the meat than in air, and edge effect diffraction can be discounted for situations where the meat is contacting the microwave antenna. Reducing the measurement area brings two advantages.

i) Smaller samples of meat are required for experimentation and better match the intended real-world application; and

ii) Meat edge reflection variations will be reduced and will further improve the linearity of the reflection to leanness association.

4.3 Recommended Path Forward

The following steps are required to make a commercial on-line microwave leanness conveyor instrument available in the market;

i) Determine whether the instrument is to incorporate a conveyor or whether it is to be retro-fitted on to existing conveyors. This will require market and technical input;

ii) Design a suitable under-belt interface and it's connection to a Keam Holdem industrial reflection coefficient measuring instrument.

iii) Produce a prototype instrument together with a user interface suitable for a meat plant. This needs to address automatic triggering and improve the instrument's measuring speed to handle conveyor belt speeds up to one meter per second.

iv) Calibrate the instrument and repeat the experiments documented here;

v) Correct the design for any minor issues remaining after the new trial; and

vi) If successful, produce and implement a marketing plan for the commercial introduction of the technique.

4.4 Meat Pipe Applications

The accuracy of VE2 has been demonstrated measuring minced meat hand placed in its sensor pipe. The path to VE2 commercialisation requires the following.

i) Confirm the diameter of pipe commonly used to pump meat in real-world factories. Modify the VE2 accordingly (Keam Holdem currently have designs for 4 inch and 8 inch pipe systems.)

ii) Conduct an in-factory field trial on mince and size-reduced product to demonstrate accuracy with continually moving product under pressure. The field trial can also solve questions such as how samples are extracted for independent CL testing and how the instrument performs between industrial cleaning cycles. The reason this trial is recommended to be conducted in a grinding factory is because the product volume needed is likely to be greater than could be obtained elsewhere.