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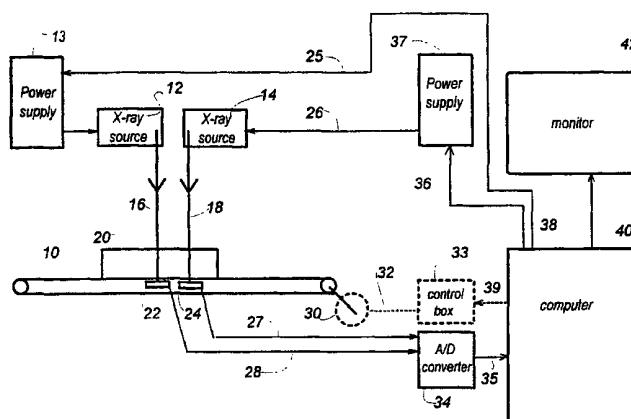
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(54) Title: **METHOD AND APPARATUS FOR DETERMINATION OF PROPERTIES OF FOOD OR FEED**



(57) Abstract: A method and apparatus for determination of properties of a medium of food or feed, such as the fat content of meat, by use of dual X-ray absorptiometry, the medium being a raw material of food or feed, a product or intermediary product of food or feed, or a batch, sample or section of the same, specifically for online use in a slaughter house. The method comprises scanning substantially all of the medium by X-ray beams (16, 18) having at least two energy levels, including a low level and a high level, detecting the X-ray beams having passed through the medium for a plurality of areas (pixels) of the medium, for each area calculating a value, A_{low} , representing the absorption in the area of the medium at the low energy level, for each area calculating a value, A_{high} representing the absorption in the area of the medium at the high energy level. The accuracy of the determination is improved considerably by generating for each area a plurality of values being products of the type $A_{low}^n * A_{high}^m$ wherein n and m are positive and/or negative integers or zero, and predicting the properties of the medium in this area by applying a calibration model to the plurality of values, wherein the calibration model defines relations between the plurality of values and properties of the medium.

Title

Method and apparatus for determination of properties of food or feed

5 **Technical field**

The present invention relates to X-ray analysis, and more specifically to the determination of properties of food or feed, such as the fat content of meat.

Background art

10 X-ray analysis for determining the fat content of meat has been known for several years. Such examples are described in numerous documents. US 4,168,431 (Henriksen) discloses a multiple-level X-ray analysis for determining fat percentage. The apparatus includes at least three X-ray beams at different energy levels. DK PS 172 377 B1 discloses detection means for X-rays as
15 well as a system for determination of properties of an item by use of X-rays. The system operates at a single energy level and applies two detection means separated by a X-ray attenuating material.

WO 92/05703 discloses a method and device for cutting food products. The positioning of suitable
20 cuts are guided by use of X-ray scanning showing the distribution of tissue type in the product. US 5,585,603 discloses a method and system for weighing objects using X-rays. A continuous X-ray analysis for a meat blending system is known from US 4,171,164 (Groves et al). The percentages of fat in two meat streams are determined by passing a beam of polychromatic X-rays through the streams, measuring both the incident and the attenuated beams.
25 US 4,504,963 discloses an apparatus, system and method for determining the percentage of fat in a meat sample through use of X-ray radiation techniques. An automatic calibration is obtained by use of three incident beams, all at same energy level. Validation of body composition by dual energy X-ray absorptiometry is described in Clinical Physiology (1991) 11, 331-341.(J. Haarbo, A. Gotfredsen, C. Hassager and C. Christiansen). Further studies on bodies are reported in Am. J.
30 Clinical Nutrition 1993: 57:605-608. (Ole Lander Svendsen, Jens Haarbo, Christian Hassager, and Claus Christiansen).

Recently analysis of meat has been reported in Meat Science Vol. 47, No 1/2, 115-124, 1997 (A. D. Mitchell, M. B. Solomon & T. S. Rumsey). Another analysis on pork carcasses is reported by
35 Mitchell et al., J. Anim. Sci. (1998), vol. 76, pp 2104-2113. However, on page 2113 of this analysis it is specifically concluded that the X-ray analysis is too slow for compatibility with on-line processing. None of the above-mentioned prior art has so far lead to an efficient apparatus fulfilling the needs in a slaughterhouse. Generally the prior art shows difficulties when measuring

layers of varying thickness, specifically thin layers adjacent to thick layers. Further the prior art is unable to measure and provide results as fast as required to be useful for online processing.

The presently applied apparatus in most slaughterhouses is a Continuous Fat Analyser (Wolfking A/S, Denmark) and Infratec 1265 (Foss Tecator AB, Sweden) using NIR technology. Also applied is Anyl-Ray (The Kartridg Pak Co., Iowa) using a single energy X-ray on a sample of well-defined weight or volume.

It is an object of the present invention to provide a method and apparatus enabling a faster and more accurate determination than hitherto known, of the fat content in a food or feed product, such as a batch of meat trimmings, allowing creation of specific products (such as sausages or minced meat) having a desired content of fat, which is much more accurate than presently possible.

The present invention also applies regression analysis and multivariate calibration. Such analysis is known from e.g. the applicant's own WO 95/16201 disclosing the Determination of extraneous water in milk samples using regression analysis and multivariate calibration. Further, the applicant's WO 98/43070 discloses Measurement of acetone in milk using IR spectroscopy and multivariate calibration. US 5,459,677 discloses a calibration transfer for analytical instruments. The applicant's WO 93/06460 discloses an infrared attenuation measuring system, including data processing based on multivariate calibration techniques, and the applicant's US 5,252,829 discloses a determination of urea in milk with improved accuracy using at least part of an infrared spectrum.

Disclosure of the invention

The present invention relates to a method of determining properties a medium of food or feed, such as the fat content of meat, by use of dual X-ray absorptiometry, the medium being a raw material of food or feed, a product or intermediary product of food or feed, or a batch, sample or section of the same, the method comprising - scanning substantially all of the medium by X-ray beams having at least two energy levels, including a low level and a high level, - detecting the X-ray beams having passed through the medium for a plurality of areas (pixels) of the medium, - for each area calculating a value, A_{low} , representing the absorbance in the area of the medium at the low energy level, - for each area calculating a value, A_{high} representing the absorbance in the area of the medium at the high energy level, *characterised by* for each area generating a plurality of values being products of the type $A_{low}^n * A_{high}^m$ wherein n and m are positive and/or negative integers or zero, and predicting the properties of the medium in this area by applying a calibration model to the plurality of values, wherein the calibration model defines relations between the plurality of values and properties of the medium.

The advantage over the prior art is a more accurate determination of the properties, such as the fat content in the medium. The accuracy is specifically improved over the prior art when

measuring layers of varying thickness. A further advantage is due to the fact that using the method according to the invention almost the whole product is measured instead of a sampling. Generally, when using sampling in an inhomogeneous medium the extraction of a sample will introduce an error, because the sample may not be representative.

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Preferably the plurality of values includes values $A_{\text{low}}^{n1} / A_{\text{high}}^{m1}$, wherein $n1$ and $m1$ are positive integers. Further on it is preferred that the plurality of values includes the values A_{low} , A_{high} , A_{low}^2 , A_{high}^2 , and $A_{\text{low}} / A_{\text{high}}$ and/or at least one of the values $A_{\text{low}} * A_{\text{high}}$; $A_{\text{low}}^2 * A_{\text{high}}$; $A_{\text{low}} * A_{\text{high}}^2$ and/or at least one of the values $A_{\text{low}} * A_{\text{high}}$; $A_{\text{low}}^2 * A_{\text{high}}$; $A_{\text{low}} * A_{\text{high}}^2$; $A_{\text{low}}^2 * A_{\text{high}}^2$; $A_{\text{low}} * A_{\text{high}}^4$ and $A_{\text{low}}^2 * A_{\text{high}}^4$ and/or at least one of the values $A_{\text{low}}^2 / A_{\text{high}}$; $A_{\text{low}} / A_{\text{high}}^2$ and $A_{\text{low}}^2 / A_{\text{high}}^2$; $A_{\text{low}}^3 / A_{\text{high}}^2$; $A_{\text{low}}^4 / A_{\text{high}}^2$; $1 / A_{\text{high}}^4$; $A_{\text{low}}^4 / A_{\text{high}}^3$; $A_{\text{low}}^3 / A_{\text{high}}^4$ and $A_{\text{low}}^4 / A_{\text{high}}^4$.

Practical experiments have proved that such values contribute considerably to improve the accuracy.

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15 Preferably the calibration model is obtained by use of a regression method being included in the group comprising Principal Component Regression (PCR), Multiple Linear Regression (MLR), Partial Least Squares (PLS) regression, and Artificial Neural Networks (ANN).

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The present invention further relates to an apparatus for the determination of properties of a medium, such as the content of a component in the medium, the medium comprising a raw material of food or feed, a product or intermediary product of food or feed, or a batch, sample or section of the same, the apparatus comprising means (12, 14) for emitting at least two X-ray beams (16, 18) at two different energy levels, means for directing the at least two X-ray beams towards and through the medium, X-ray detection means (22, 24) covering a plurality of areas for detecting the two beams (16, 18) after passing through the medium, means (27, 28, 34, 35) for transferring and converting output signals from the detection means (22, 24) into digital data set for input to data processing means (38) for receiving, storing and processing the at least two data set representing X-ray images at the at least two different energy levels, the apparatus further comprising means for synchronising the at least two data sets and

30 the data processing means including means for calculating values representing the absorbances (A_{low} , A_{high}) in each area of the medium at the at least two energy levels, *characterised in that* the data processing means comprise means for generating a plurality of values being products of the type $A_{\text{low}}^n * A_{\text{high}}^m$ wherein n and m are positive and/or negative integers or zero, and means for predicting the properties of the medium in this area by applying a calibration

35 model to the plurality of values, wherein the calibration model defines relations between the plurality of values and properties of the medium.

The advantage over the prior art is a faster and more accurate determination, which is so fast that it can be applied continuously on a process line in a slaughterhouse.

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The present invention further relates to a method for calibration of an apparatus according to any of the claims 9 - 22, *characterised by* comprising preparation of a plurality of calibration samples consisting of specified food or feed products, such as minced pork meat, of various well-defined heights and properties, measuring the plurality of calibration samples in the apparatus, thereby obtaining data representing two X-ray responses of each sample, each response comprising a plurality of pixels, and wherein the data of each pixel, or the mean of a number of neighbouring pixels, are processed using the formulas:

$$A_{\text{low}} = -\log_{10} \left[\frac{I_{\text{sample}}(\text{low}) - I_{\text{dark}}(\text{low})}{I_{\text{air}}(\text{low}) - I_{\text{dark}}(\text{low})} \right]$$

$$A_{\text{high}} = -\log_{10} \left[\frac{I_{\text{sample}}(\text{high}) - I_{\text{dark}}(\text{high})}{I_{\text{air}}(\text{high}) - I_{\text{dark}}(\text{high})} \right]$$

or similar expressions for calculation of values representing the absorbance in an area of the medium above a pixel or a number of neighbouring pixels,

generating a plurality of values of the type $A_{\text{low}}^n * A_{\text{high}}^m$, wherein n and m are positive and/or negative integers and/or zero,

correlating - by use of multivariate calibration methods, such as Artificial Neural Networks (ANN), or PCR, MLR or PLS regression - the data set for all/or a plurality of calibration samples to the properties determined by other means, such as a reference method, - in order to determine a number of calibration coefficients, providing a calibration model comprising the number of determined calibration coefficients.

The invention further relates to a method of predicting the fat content of meat, comprising use of a calibration model obtained by a method according to claim 23 or 24. The invention also relates to an apparatus according to any of the claims 9 - 22, comprising a calibration model determined by a method according to claim 23 or 24.

By use of the present invention it is possible - more accurate and more rapidly than hitherto known - to determine the fat content of a random number of meat lumps (such as trimmings or cuts) of various sizes in a container (or similar means for enclosing or carrying a load of meat) or directly on a conveyor belt. The measurement may be performed within a fairly short time, such as a few seconds, e.g. about 4.5 or 9 seconds per container, each container having a volume of e.g. about 0.1 m³. Preferably, a smaller volume, about e.g. 25 kg meat, is arranged in each container. Accordingly, the method and apparatus may be applied for on-line control of the production of various meat products, such as minced meat, and more specifically where minced meat is produced from meat trimmings of various sizes.

According to the applicant's best knowledge multivariate calibration techniques have never been applied to X-ray analysis of meat, nor to X-ray analysis in general. The use of multivariate techniques solves a specific problem present when using the techniques according to the prior art. The known apparatus becomes highly inaccurate when measuring on a combination of thin and thick layers. When measuring meat lumps of various sizes the thickness of the layers through which the X-ray has to pass will vary considerably from 0 or almost 0 to a specified maximum. The use of a plurality of values allows a better accuracy of such measurements than hitherto known.

Brief description of the drawings

Figure 1 shows as an example a system according to the invention

Figure 2 shows a preferred embodiment of an X-ray apparatus according to the invention

Figure 3 shows a simulation of a system comprising one source and a combination of two filters.

Figure 4 shows cross-validated X-ray fat predictions versus reference fat content of 32 calibration samples when performing a simple univariate regression of A_{low}/A_{high} against the reference fat content of the samples.

Figure 5 shows cross-validated X-ray fat predictions versus reference fat content of 32 calibration samples when performing a PLS calibration with 5 PLS factors (based on 11 variables) against the reference fat content of the samples.

Figure 6 shows cross-validated X-ray areal densities versus reference areal density of 32 calibration samples when performing a simple univariate regression of A_{high} against the reference areal densities of the samples.

Figure 7 shows cross-validated X-ray areal densities versus reference areal density of 32 calibration samples when performing a PLS calibration with 1 PLS factor (based on 2 variables) against the reference areal densities of the samples.

Figure 8 shows Fat predicted by X-ray in 99 points of a meat sample.

Figure 9 shows Areal density predicted by X-ray in 99 points of a meat sample.

Figure 10 shows Fat (in g/cm^2) predicted by multiplication of the fat content (Figure 8) by the areal density (Figure 9) in 99 points of a meat sample.

Figure 11 shows a flow diagram illustrating the measuring process.

Figure 12 shows a typical meat sample in a plastic container.

Figure 13 shows a typical low energy X-ray transmission image of a meat sample as shown in figure 12.

Figure 14 shows a typical high energy X-ray transmission image of the same meat sample.

Figure 15 is an image illustrating a calculated areal density for each individual pixel.

Figure 16 is an image illustrating a calculated fat content for each individual pixel.

Figure 17 is an image illustrating a calculated "fat map" for a meat sample of 36 % fat.

Figure 18 shows a reference versus predicted plot for 50 scans.

Detailed description of a preferred embodiment and method

The following description discloses as an example a preferred embodiment of the invention using two X-ray sources. The apparatus is designed for being installed in relation to a production line in a slaughterhouse. Figure 1 shows a schematic diagram of an embodiment of a measurement system according to the invention. Figure 2 illustrates the principle of the presently preferred X-ray apparatus. Figure 2 shows only the active operating portions of the X-ray equipment. For purpose of clarity, all protective shielding or screening and all casings are deleted from the drawing. The equipment comprises or is located in close relation to a conveyor 10. Two X-ray sources 12, 14 are arranged above the conveyor 10. From the two sources 12, 14 X-ray beams 16, 18 are directed towards detectors 22, 24 arranged below the conveyor. The conveyor may be split into two separate conveyors spaced to allow free pass of the X-rays and to leave an open space for location of detectors 22, 24. Alternatively the conveyor belt should be made from a material showing a low absorbance of X-rays, e.g. polyurethane or polypropylene. The food or feed to be measured is arranged in an open container or box 20, preferably also composed by a material showing low absorbance of X-rays. Obviously in an alternative arrangement the sources could be located below the conveyor and the detectors above the conveyor.

The operational speed of the conveyor is preferably substantially constant. The items, motor 30, control box 33, and cables 32, 39, shown by phantom lines in Figure 1, indicate that the operation of the conveyor optionally may be controlled by the computing means 38. The conveyor may include position measuring means, e.g. an encoder installed on a conveyor driving shaft. Alternative means may be a laser or radar detection or marks on the conveyor belt. It is essential to the present method that the data representing the two X-ray images can be synchronised. Such synchronisation may however be obtained in many ways, including mathematical post-processing of the images.

The equipment used in the present example consists of two constant potential X-ray sources 12, 14, one at low energy (e.g. 62 kV/5 mA) and another at high energy (e.g. 120 kV/3 mA), both with an appropriate filtration (e.g. using 0.25 and 1.75 mm of copper, respectively) narrowing the spectral range of the radiation emitted from the polychromatic sources. The two sources are spatially separated to avoid interference between them, i.e. to avoid that radiation from one source is detected as if it originated from the other. The radiation from either source is collimated by a lead collimator. In this way two fan-shaped beams of X-rays 16, 18 are directed through container 20 comprising a sample or batch of the food or feed product towards detectors 22, 24, e.g. Hamamatsu C 7390. Alternatively the meat lumps may be arranged loosely on a conveyor band.

Further, the two separate sources may be replaced by a combination of one source and two filters emitting a low energy and a high energy beam. The resulting source spectra are shown in Figure

3. However the preferred embodiment applies two separate sources 12, 14 driven by separate power supplies 13, 37.

Both X-ray sources 12, 14 are associated with an array of detectors 22, 24 covered with a scintillating layer converting the transmitted radiation into visible light that can be measured by the detectors 22, 24. The scintillating layer may consist of e.g. cadmium telluride, mercury iodide, and/or gadolinium oxysulphide. The pixels used in the presently preferred embodiment have the dimensions $1.6 \times 1.3 \text{ mm}^2$ and are arranged as an array of 384 pixels with a pitch of 1.6 mm.

These dimensions are only stated as an example. Other dimensions may be applied. The pixels convert the amount of transmitted light into analogue signals that are passed through cables 27, 28 to an analogue-to-digital converter 34 which is connected through cable 35 to a computing means 38 capable of performing the successive calculations. A monitor 42 may be connected through cable 40 to the computing means to show results or details of the operation. The computing means 38 may include means for controlling the supply of power through means 36, 37, 26 and 25, 13, 15 to the X ray sources 12, 14. The monitor 42 and the computing means 38 may comprise a Personal Computer, preferably including at least one Pentium processor and/or a number of digital signal processors.

Operation:

A container 20, comprising e.g. meat trimmings from a cutting section of the slaughterhouse, is received on the conveyor 10. The container is moved with a fairly constant speed of e.g. about 5 - 100 cm per second, such as 10-50 cm, e.g. 30 cm per second past the fan shaped beams 16, 18 and the arrays of detectors 22, 24 in a controlled manner in order to generate two images of the sample or batch, one at a low X-ray energy and another at a high energy. All data representing the two images are stored in the computer 38.

Treatment of the collected data

Fig. 11 represents a flow chart illustrating the measurement and data treatment. As stated above, two X-ray images of each container, comprising a batch of food or feed e.g. meat, are obtained. The signals at the pixels are I_{low} and I_{high} at low and high X-ray energies, respectively, (110, 112 in Figure 11). Furthermore, the so-called "dark signals" (i.e. the signal from the detectors when no radiation reaches them), $I_{\text{dark}}(\text{low})$ and $I_{\text{dark}}(\text{high})$, and the "air signals" (i.e. the signal from the detectors when no sample is present in the sampling region), $I_{\text{air}}(\text{low})$ and $I_{\text{air}}(\text{high})$, are collected for each pixel at both X-ray energies (102 in Figure 11). Preferably these data are collected repetitively in the intervals between the passage/passing of meat containers, i.e. the dark signals and air signals are measured repetitively, e.g. at regular intervals during a day to adjust for any drift of instrument performance.

Now referring to 114 in Figure 11, these signals are transformed into absorbance units by using the following formulas:

$$A_{\text{low}} = -\log_{10} \left[\frac{I_{\text{sample}}(\text{low}) - I_{\text{dark}}(\text{low})}{I_{\text{air}}(\text{low}) - I_{\text{dark}}(\text{low})} \right]$$

$$A_{\text{high}} = -\log_{10} \left[\frac{I_{\text{sample}}(\text{high}) - I_{\text{dark}}(\text{high})}{I_{\text{air}}(\text{high}) - I_{\text{dark}}(\text{high})} \right]$$

From these two values, a plurality of values can be generated e.g. : A_{low} ; A_{high} ; A_{low}^2 ; A_{high}^2 ; $A_{\text{low}} \times A_{\text{high}}$; $A_{\text{low}}^2 \times A_{\text{high}}$; $A_{\text{low}} \times A_{\text{high}}^2$; $A_{\text{low}}/A_{\text{high}}$; $A_{\text{low}}^2/A_{\text{high}}$; $A_{\text{low}}/A_{\text{high}}^2$; $(A_{\text{low}}/A_{\text{high}})^2$; ...

or in a more generalised manner: $A_{\text{low}}^n * A_{\text{high}}^m$,

wherein n and m are positive and/or negative integers and/or zero,

These values are used as the input for the calibration routine establishing a relationship between the collected data and the component (e.g. the fat content) or the property (e.g. the areal density) of interest.

It is essential that a value A_{low} for a specific pixel measuring the low energy transmittance through a specific area of the medium is matched to the value A_{high} for the pixel measuring the high energy transmission through exactly the same area of the medium. This can be accomplished by ensuring a synchronisation of the pictures as mentioned below.

If the low and high energy images are not perfectly aligned, i.e. if a specific region of the sample does not show up at exactly the same positions in the two images, large errors may result. This problem may occur e.g. if the two line scan detectors (22, 24) are not synchronised. A possible solution to this problem is to calculate the correlation between the two images using various shifts between them and thereby finding the shift at which the correlation is at a maximum, followed by a correction of one of the images by this shift. It is however preferred to synchronise the line scanning e.g. by the use of a position measuring means, or by tight control of the conveyor speed.

The following example explains how to generate a calibration model.

Example: Calibration against fat content and areal density

A set of 32 calibration samples consisting of minced pork meat were prepared. They were frozen in blocks of varying heights (5, 10, 15, and 20 cm) with horizontal dimensions of $10 \times 10 \text{ cm}^2$. Their fat content (percentage) which ranged from 2.6 to 70.9 %, were later determined by use of a wet

chemistry method. The heights and fat contents (percentage), together with the fat-dependent density of meat, were used for calculating the areal densities of all 32 samples, ranging from 4.8 to 21.0 g/cm².

5 The frozen meat blocks were measured in the aforementioned X-ray equipment, yielding two images of each sample. The data points (pixels) of these images were treated according to the steps described above. To avoid random noise from influencing the calibration results, the 11 values generated from the original absorbance values were averaged over all pixels in the image. This could only be done since the samples were homogeneous and of fixed height.

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This data set consisting of 11 variables obtained for all 32 samples was correlated against the fat content (percentage) measured by a reference method and the areal densities using the Partial Least Squares (PLS) regression method. This, and other similar multivariate calibration methods are well known (Martens and Næs: Multivariate Calibration, 2nd ed., Wiley (1992)).

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The calibrations were validated using full cross-validation, i.e. one sample at a time was removed from the data set for validation while the remaining 31 samples were used for calibration. This procedure was repeated for all samples, and validation results were generated by combining the validation results for all 32 samples.

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The traditional way of building an X-ray calibration model for fat in meat is by correlating the $A_{\text{low}}/A_{\text{high}}$ ratio to the fat reference results (Haardbo et al., Clin. Phys. (1991), vol. 11, pp. 331-341 or Mitchell et al. J. Anim. Sci. (1998), vol. 76, pp. 2104-2114). This method is, however, sensitive to the thickness (or areal density) of the sample and is therefore not useful with the range of sample heights (from 5 to 20 cm) of interest in the present context. This is evident from Figure 4, where X-ray fat predictions using only the $A_{\text{low}}/A_{\text{high}}$ ratio are plotted against the fat reference results. The prediction error (expressed as the Root Mean Square Error of Prediction, RMSEP) is 14.7 % in this case.

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30 Using the method according to the invention, with e.g. 11 or more variables generated from the original two absorbances in combination with a PLS regression with 5 PLS-factors, the plot presented in Figure 5 is obtained. In this case, the prediction error (RMSEP) is as low as 1.0 %, thus showing the benefits of using the PLS method in combination with the new variables.

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The method can also be applied for the determination of the areal density of the sample. According to the prior art the areal density is determined by correlating A_{high} to the reference areal density. The result of such a calibration model is presented in Figure 6, where the agreement between the areal density determined by X-ray and the reference results is very good. The prediction error (RMSEP) is 0.30 g/cm² in this case. When using the method according to the

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invention, i.e. using both measured absorbances, A_{low} and A_{high} , in combination with a PLS

regression with 1 factor, the result presented in Figure 7, and a prediction error (RMSEP) of 0.28 g/cm², is obtained. This is only a slight improvement, but the use of two variables instead of one provides the user with a further advantage: the possibility of detecting incorrect measurements (e.g. if one of the two X-ray sources shows a sudden drop in intensity, or if a pixel is not responding). This is because discrepancies from the relationship between A_{low} and A_{high} can easily be detected by the PLS model. Such outlier detection is not possible if only one absorbance is used. This possibility is very relevant and advantageous when using CCD detector wherein a single pixel may deteriorate fairly abruptly.

- 10 The calibration models developed in this way can be used for future predictions of the fat content and areal density in a given point in an inhomogeneous meat sample as well as for determination of the mean fat content of a large meat sample.

Prediction of the fat content of an unknown meat sample

15 The following example will demonstrate the use of the calibration models in practice where samples are inhomogeneous and of varying thickness. The purpose is to predict the mean fat content of the samples. Therefore the procedure involves the following steps as shown in Figure 11:

- 20
1. Regular measuring of I_{dark} and I_{air} , 102
 2. Arranging a batch or stream of meat (or other food or feed product) on a conveyor passing through the X-ray apparatus, 104
 3. Scanning the batch or stream by X-ray beams at two different energy levels, 106, 108,
 - 25 4. Detecting signals representing a plurality of X-ray intensities, using the detectors 22, 24 in Figures 1, 2 110, 112
 5. Recording data representing the detected signals 114.
 6. Calculate A_{low} and A_{high} for all pixels 114, (optionally, a smoothing of the picture may be included.)
 - 30 7. Co-ordinate (match) A_{low} values and A_{high} values 114, if necessary.
 8. Calculate derived expressions $A_{low}^n * A_{high}^m$ 114.
 9. Calculate the fat content (percentage) and preferably the areal density for all points (pixels) obtained from the scanings, using a fat calibration model generated as described above 116.
 10. Multiply the fat content (percentage) and areal density at each point, in order to generate a
 - 35 "fat map" (in g/cm²) of the batch or stream of food or feed 116.
 11. Add all points in the "fat map" to give the total fat weight (F_{total}) 116.
 12. Add all areal densities for the sample to give the total weight (W_{total}) 116.
 13. Calculate the average fat content (percentage) as the ratio F_{total}/W_{total} 116.

Optionally, two more steps may be included between step 6 and 7:

If the meat lumps are arranged in a container the data should be subjected to a correction for the absorption in the bottom of the container. Such correction is preferably made at the end of step 6, providing new corrected values of A_{low} and A_{high} for all pixels.

5

A further advantageous option is smoothing of the data, e.g. in the direction of the movement. Further experience has proved that it can be advantageous to include a further data processing in step 9. In a presently preferred embodiment pixels having an areal density outside a specified interval are removed/deleted or at least disregarded in the following data processing, i.e. pixels for which the calculated areal density is extremely low or much too high, are rejected.

10

The present example shows the calculation of the fat content (percentage) for one row of 99 points only. This is done in order to make the presented plots simpler, and is easily generalised to be performed on a two-dimensional image of a meat product.

15

Example 1:

A meat sample consisting of a cubic block (dimensions: $10 \times 10 \times 10 \text{ cm}^3$) of minced pork meat was measured using the same X-ray equipment as was used for measuring the calibration samples.

20

The first two steps of the prediction procedure are shown in Figure 8 (predicted fat content (percentage)), Figure 9 (predicted areal density, step 9), and Figure 10 (the "fat map", step 10). There is clearly a variation in both fat content and areal density over the sample, so the results from all sample points are needed in order to obtain an accurate estimate of the mean fat content of the sample.

25

The sum of all points in the "fat map" (step 11), F_{total} , equals 464 g/(99 pixels), and the total weight of the sample (step 12), W_{total} , is 963 g/(99 pixels). This, in turn, results in a predicted mean fat content of $464/963 = 48.2 \%$ (step 13), not far from the true fat content, which was determined later as 49.2 % by a reference method.

30

Example 2:

This example is an extension of the results stated above. The present example involves the prediction of the fat content of samples consisting of approximately 25 kg of meat in plastic containers.

35

Ten samples of meat ranging from 11.5 to 84.6 % fat were obtained from a meat processing plant. The amount of meat in each container ranged from 20 to 30 kg, the sample homogeneity ranging from ground meat to meat pieces of 5 kg each. A typical sample consisting of 36 % fat trimmings arranged in a presently preferred container (dimensions: $70 \times 40 \times 17 \text{ cm}^3$) is shown in Figure 12.

40

Each of these ten samples were scanned by the instrument five times over a period of two days. Before each new scan the contents of the container was reorganised, i.e. the meat pieces were moved around without changing the total content of the container. This was done in order to
5 check the repeatability of the measurement. A total of 50 X-ray scans, each consisting of a low and a high energy image of 306×1836 data points, were thus gathered. Two typical transmission images of a sample are shown in Figures 13 and 14.

All 50 scans were subjected to the prediction steps according to the invention, using a calibration
10 model based on frozen meat samples. The calculated fat content and areal density for each individual pixel (step 9), as well as the "fat map" (step 10) for one sample are shown in Figures 16, 15, 17. The negative fat predictions are due to a relatively low signal-to-noise ratio on the individual pixels. This is, however, no problem, as the final averaging of the results reduces this error by orders of magnitude. From these images, the total fat content of the samples was
15 calculated. The pooled repeatability standard deviation, s_r , for the five different scans of the same sample was 0.25 %.

After this experiment had been carried out the samples were homogenised and a number of subsamples were analysed by the reference method for fat in meat (Schmid-Bondzynski-Ratzlaff,
20 SBR method). These reference results were compared to the predictions obtained above, resulting in an accuracy (Root Mean Square Error of Prediction, RMSEP) of 0.81 %. The reference versus predicted plot for the 50 scans is shown in Figure 18.

Example 3

To demonstrate the advantage of the method, in terms of its ability to significantly improve the accuracy of the fat determination, a further experiment was carried out. 45 frozen meat samples with fat contents ranging from 2.4 to 72.8 % and areal densities ranging from 1 to 21 g/cm² were measured using the X-ray equipment. These samples were used for obtaining six different
30 calibration models, using various combinations of the 11 variables based on A_{low} and A_{high} described above. Subsequently, these calibration models were tested on the same data set as used in Example 2, i.e. ten meat samples of 20 to 30 kg with fat contents ranging from 11.5 to 84.6 % fat.

35 The six combinations of variables used for calibration models are shown in the table presented below, along with the resulting accuracies (RMSEP) on the calibration set (cross-validated) and the test set. Furthermore, the repeatability (s_r) on the test set was also calculated.

calibration no.	A_{low}	A_{high}	A_{low}^2	A_{high}^2	$A_{low} \times A_{high}$	$A_{low}^2 \times A_{high}$	$A_{low} \times A_{high}^2$	A_{low}/A_{high}	A_{low}^2/A_{high}	A_{low}/A_{high}^2	$(A_{low}/A_{high})^2$	RMSEP (calibration)	RMSEP (test)	s_r (test set)
1	+	+	+	+	+							9.43	1.52	0.41
2	+	+	+	+	+	+	+					7.59	3.04	0.86
3	+	+	+	+	+	+	+	+				0.93	1.09	0.26
4	+	+	+	+	+	+	+	+	+	+	+	0.79	0.81	0.25
5					+	+	+	+	+	+	+	2.30	1.17	0.23
6								+	+	+	+	3.36	3.31	0.26

From the results presented in the table the accuracy obtained when using only powers of A_{low} and A_{high} (calibration model 1) as well as products thereof (calibration model 2) are unacceptable if the method is to be used for process control within tight limits. If the A_{low}/A_{high} ratio is added, combined with powers of A_{low} and A_{high} (calibration model 3), an acceptable accuracy is obtained. However, if powers of A_{low} and A_{high} are combined with A_{low}/A_{high} and the more complex ratios (calibration model 4), even more accurate predictions result. It is also clear from calibration models 5 and 6 that of A_{low} and A_{high} and powers thereof are essential if the best possible accuracy is required.

In terms of the repeatability it is also clear that the A_{low}/A_{high} ratio has a major influence on the difference between multiple determinations of the same sample.

The example presented above demonstrates the advantages in using higher order ratios for calibration of X-ray data against fat reference results. Only orders up to two were used in the present example, but ratios of higher orders may improve the result even further. For example, when using the ratios: $(A_{low}/A_{high})^3$; $(A_{low}/A_{high})^4$; A_{low}^3/A_{high} ; A_{low}^4/A_{high} ; A_{low}^3/A_{high}^2 ; A_{low}^4/A_{high}^2 ; A_{low}^4/A_{high}^3 , an accuracy (RMSEP) of 0.67 is obtained on the calibration set.

The method may be applied to all kinds of meat, such as beef, veal, pork, buffalo, camel and lamb, game, such as rabbit, poultry, such as chicken, turkey, duck, goose and ostrich, and fish.

While a single particular embodiment of the invention has been mentioned, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, such as using more than two X-ray sources or alternative arrangements such as arranging the sources below the conveyor or sideways, and it is, therefore, contemplated to cover by the appended claims any such modifications as fall within the true spirit and scope of the invention.

Patent claims

1. A Method of determining properties a medium of food or feed, such as the fat content of meat, by use of dual X-ray absorptiometry, the medium being a raw material of food or feed, a product or intermediary product of food or feed, or a batch, sample or section of the same, the method comprising
 - scanning substantially all of the medium by X-ray beams having at least two energy levels, including a low level and a high level,
 - detecting the X-ray beams having passed through the medium for a plurality of areas (pixels) of the medium,
 - for each area calculating a value, A_{low} , representing the absorbance in the area of the medium at the low energy level,
 - for each area calculating a value, A_{high} representing the absorbance in the area of the medium at the high energy level,

characterised by

for each area generating a plurality of values being products of the type $A_{low}^n * A_{high}^m$ wherein n and m are positive and/or negative integers or zero, and predicting the properties of the medium in this area by applying a calibration model to the plurality of values, wherein the calibration model defines relations between the plurality of values and properties of the medium.
2. A Method according to claim 1, *characterised by* the plurality of values including values $A_{low}^{n1} / A_{high}^{m1}$, wherein n1 and m1 are positive integers.
3. A method according to claim 1, *characterised by* the plurality of values including the values A_{low} , A_{high} , A_{low}^2 , A_{high}^2 , and A_{low} / A_{high} .
4. A method according to claim 3, *characterised by* the plurality of values including at least one of the values $A_{low} * A_{high}$, $A_{low}^2 * A_{high}$, $A_{low} * A_{high}^2$, $A_{low} * A_{high}^4$ and $A_{low}^2 * A_{high}^4$.
5. A method according to claim 3, *characterised by* the plurality of values including at least one of the values A_{low}^2 / A_{high} , A_{low} / A_{high}^2 and A_{low}^2 / A_{high}^2 .
6. A method according to claim 3, *characterised by* the plurality of values including at least one of the values A_{low}^3 / A_{high}^2 , A_{low}^4 / A_{high}^2 , $1 / A_{high}^4$, A_{low}^4 / A_{high}^3 , A_{low}^3 / A_{high}^4 and A_{low}^4 / A_{high}^4 .
7. A method according to claim 1, *characterised by* the calibration model being obtained by use of a regression method being included in the group comprising Principal

Component Regression (PCR), Multiple Linear Regression (MLR), Partial Least Squares (PLS) regression, and Artificial Neural Networks (ANN)

8. A method according to claim 1, *characterised in that*
 - 5 the medium is arranged on a conveyor moving at substantially constant speed, and
 - the at least two X-ray beams are fanshaped, and
 - the low level beam is detected by a first linear array, being dedicated to the detection of the low energy beam, and
 - the high level beam is detected by a second linear array being dedicated to the detection of
 - 10 the high energy beam,
 - each comprising a plurality of pixels.

9. An apparatus for the determination of properties of a medium, such as the content of a component in the medium, the medium comprising a raw material of food or feed, a product or intermediary product of food or feed, or a batch, sample or section of the same,
 - 15 the apparatus comprising
 - means (12, 14) for emitting at least two X-ray beams (16, 18) at two different energy levels,
 - means for directing the at least two X-ray beams towards and through the medium,
 - X-ray detection means (22, 24) covering a plurality of areas for detecting the two beams (16,
 - 20 18) after passing through the medium,
 - means (27, 28, 34, 35) for transferring and converting output signals from the detection means (22, 24) into digital data set for input to data processing means (38) for receiving,
 - storing and processing the at least two data sets representing X-ray images at the at least two different energy levels,
 - 25 the apparatus further comprising means for synchronising the at least two data sets and the data processing means including means for calculating values representing the absorbances (A_{low} , A_{high}) in each area of the medium at the at least two energy levels,
 - characterised in that* the data processing means comprise means for generating a plurality of values being products of the type $A_{low}^n * A_{high}^m$ wherein n and m are positive
 - 30 and/or negative integers or zero, and
 - means for predicting the properties of the medium in this area by applying a calibration model to the plurality of values, wherein the calibration defines relations between the plurality of values and properties of the medium.

10. An apparatus according to claim 9, *characterised by* comprising
 - 35 at least one low energy X-ray source (12) arranged above the medium (20) for providing a fan-shaped low energy beam (16) substantially covering the width of medium and
 - at least one high energy X-ray source (14) arranged above the medium (20) for providing a fan-shaped low energy beam (16) covering the width of medium (20) and
 - 40 a first X-ray detection means (22) arranged to be exposed to the fan-shaped low energy

beam (16) and below the medium (20)

a second X-ray detection means (24) arranged to be exposed to the fan-shaped high energy beam (18) and below the medium (20)

and electronic means (34, 38, 42) including the data processing means (38) and

5 communicating with the detectors (22, 24) and arranged to

store and process data representing signals from the detection means (22, 24)

and further comprising means (10) for moving the medium (20) relative to the X-ray beams (16, 18) or visa versa.

10 11. An apparatus according to claim 9, *characterised in* that the data processing means include and/or communicate with means including data storage means comprising a calibration model prepared by use of multivariate calibration methods such as Artificial Neural Networks (ANN), or PCR, MLR or PLS regression analysis.

15 12. An apparatus according to claim 9, *characterised by* comprising at least two sources (12, 14) emitting X-rays of two different energy levels.

13. A method according to claim 1, *characterised by* the two energy levels comprising a low energy level in a range between 35 and 75 keV, preferably between 45 and 70 keV and
20 most preferred about 62 keV, and a high energy level in a range between about 60 and 140 keV, preferably between 80 and 130 keV and most preferred about 120 keV.

14. An apparatus according to claim 9, *characterised by* comprising filter means located in each of the beams (16, 18).

25 15. An apparatus according to claim 9, *characterised by* comprising one X-ray source and two filter means splitting the beam into two beams of X-rays at two different energy levels.

30 16. An apparatus according to claim 9, *characterised in that* the means (12, 14) for emitting at least two X-ray beams, the means for directing the at least two X-ray beams and the X-ray detection means (22, 24) are mutually fixed.

17. An apparatus according to claim 9, *characterised by* comprising means (12, 14)
35 for emitting spatially separated fan-shaped beams (16, 18).

18. An apparatus according to claim 9, *characterised in* that the detection means (22,24) are covered by a scintillating layer, e.g. cadmium telluride, mercury iodide, and/or gadolinium oxysulphide.

19. An apparatus according to claim 9, *characterised by* comprising conveyor means (10) arranged to carry container means (20), such as a tray or an open box, adapted to accommodate a random number of meat lumps of various sizes to be analysed, the conveyor means being arranged to let the container means (20) pass the at least two fan-shaped X-ray beams (16, 18).
5
20. An apparatus according to claim 19, *characterised by* comprising conveyor means (10) wherein the conveyor belt is made from a material showing a low absorption of X-rays, and/or is split into two separate, spaced parts, the detector means (22, 24) being arranged in an open space between the two parts.
10
21. An apparatus according to claim 9, *characterised by* comprising conveyor means (10) adapted to accommodate a continuous flow of meat lumps of various sizes to be analysed, the conveyor means being arranged to let the meat lumps pass the at least two fan-shaped X-ray beams (16, 18).
15
22. An apparatus according to any of the claims 9 - 21, *characterised by* being arranged to perform the following steps:
scan at least a section of a medium by X-ray beams having at least two energy levels,
20 store data representing at least two X ray images of the medium,
calculate the fat content and/or areal density for all points (pixels) obtained from the scanning by use of multivariate calibration models generated in a previously performed calibration step,
multiply the fat content and areal density at each point, in order to generate a "fat map" (in g/cm^2) of the sample,
25 add all points in the "fat map" to give the total fat weight (F_{total}) of the sample,
add all areal densities for the sample to give the total weight (W_{total}) of the sample,
calculate the average fat content of the sample as the ratio $F_{\text{total}}/W_{\text{total}}$.
23. A method for calibration of an apparatus according to any of the claims 9 - 22,
30 *characterised by* comprising
preparation of a plurality of calibration samples consisting of a specified medium comprising food or feed products, such as minced pork meat, of various well defined areal densities and properties,
measurement of the plurality of calibration samples in the apparatus, thereby obtaining data
35 representing two X-ray responses of each sample, each response comprising a plurality of pixels, and wherein the data of each pixel or the mean of a number of neighbouring pixels are processed to calculate the absorbances A_{low} and A_{high} in the medium above said pixel or pixels,
generating a plurality of values of the type $A_{\text{low}}^n * A_{\text{high}}^m$, wherein n and m are positive
40 and/or negative integers and/or zero,

correlating – by use of multivariate calibration methods, such as Artificial Neural Networks (ANN) or PCR, MLR or PLS regression - the data set for all/or a plurality of calibration samples to the properties determined by other means, such as a reference method, - in order to determine a number of calibration coefficients,

5 providing a calibration comprising the number of determined calibration coefficients.

24. A method according to claim 23, *characterised in* that all calibration samples are prepared in such a manner that they are homogeneous and of fixed areal densities, and further by averaging each of the values over all pixels at least in a defined portion of the
10 images.

25. A method of predicting the fat content of meat, *characterised by* use of a calibration model obtained by a method according to claim 23 or 24.

15 26. An apparatus according to any of the claims 9 - 22, *characterised by* comprising a calibration model determined by a method according to claim 23 or 24.

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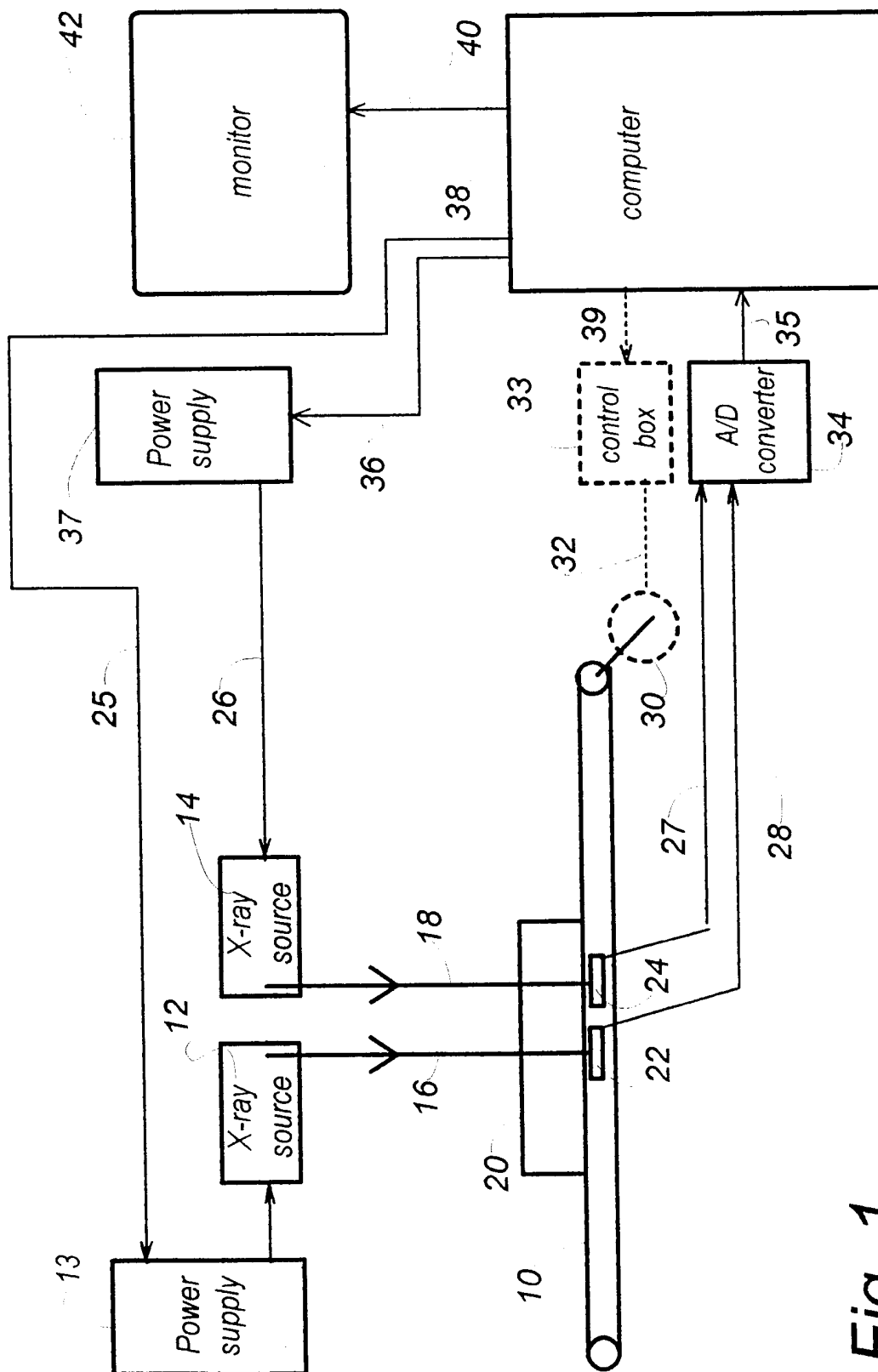


Fig. 1

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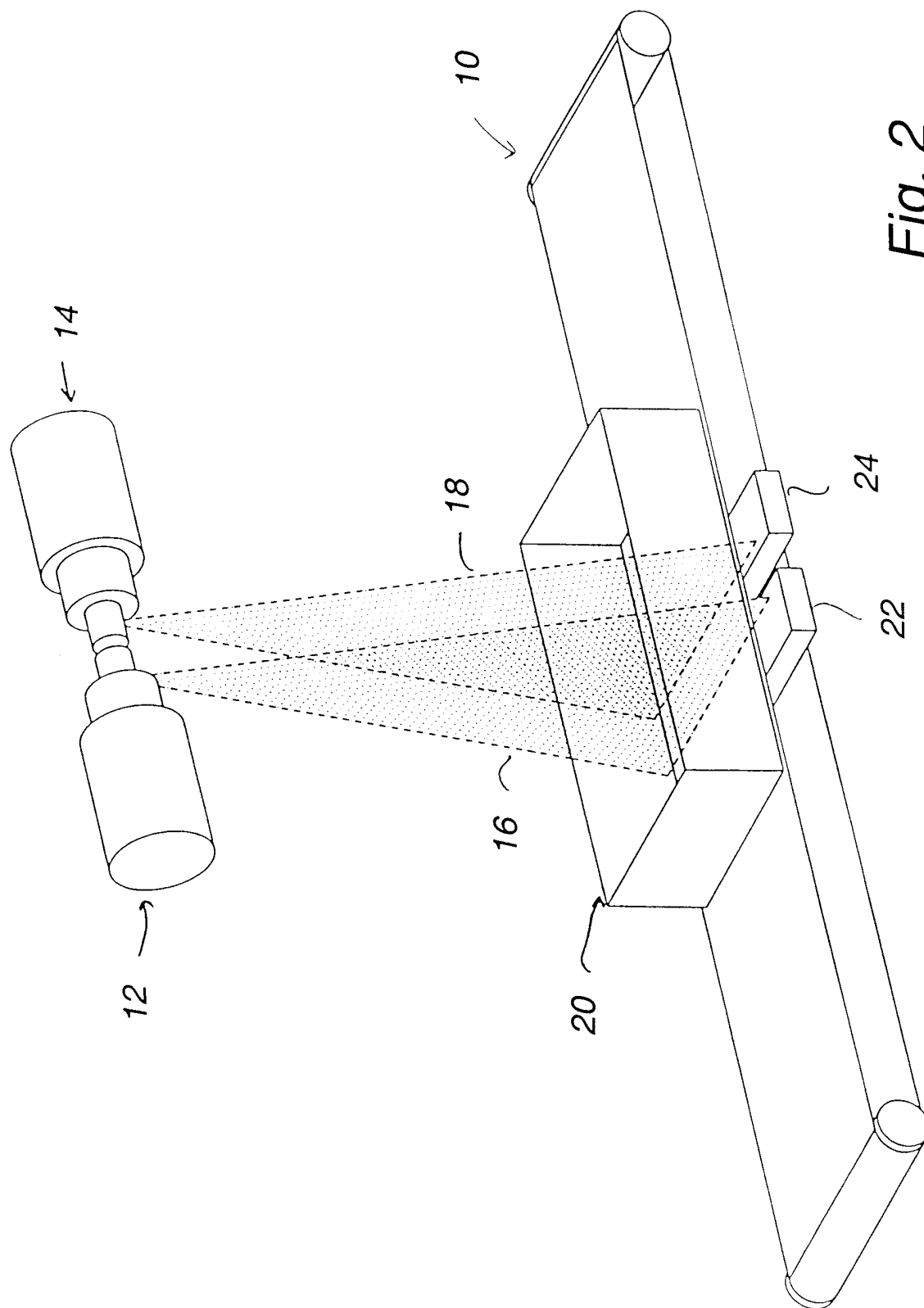
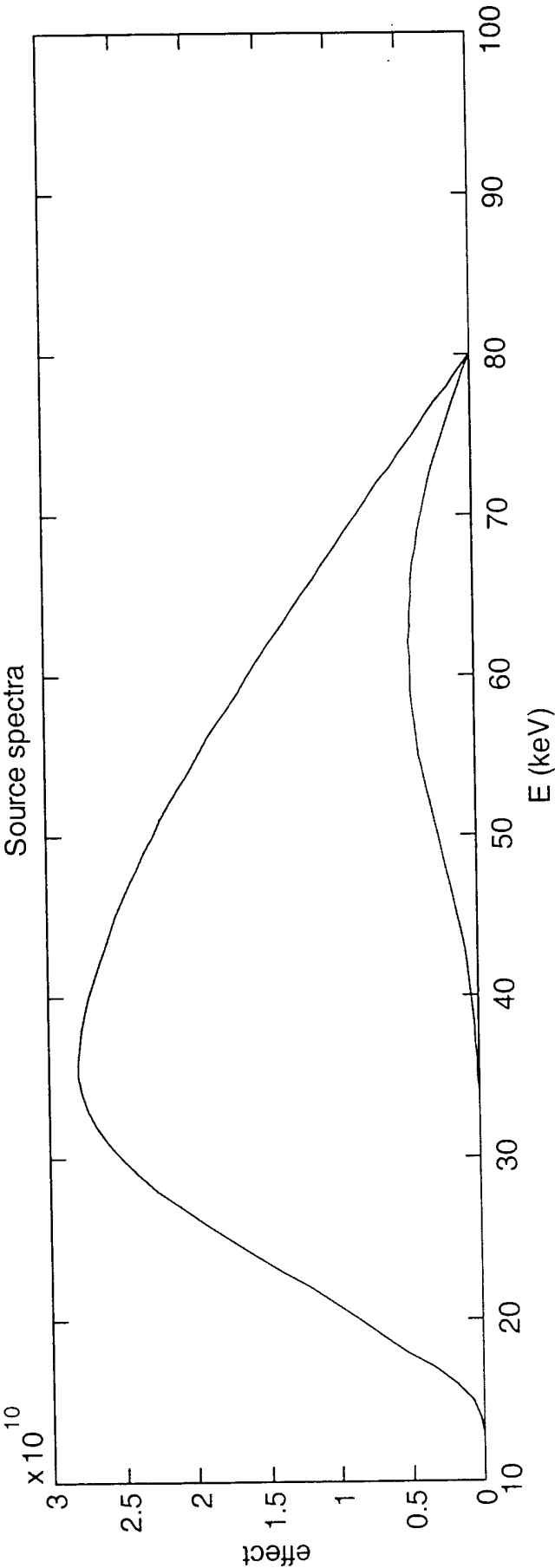
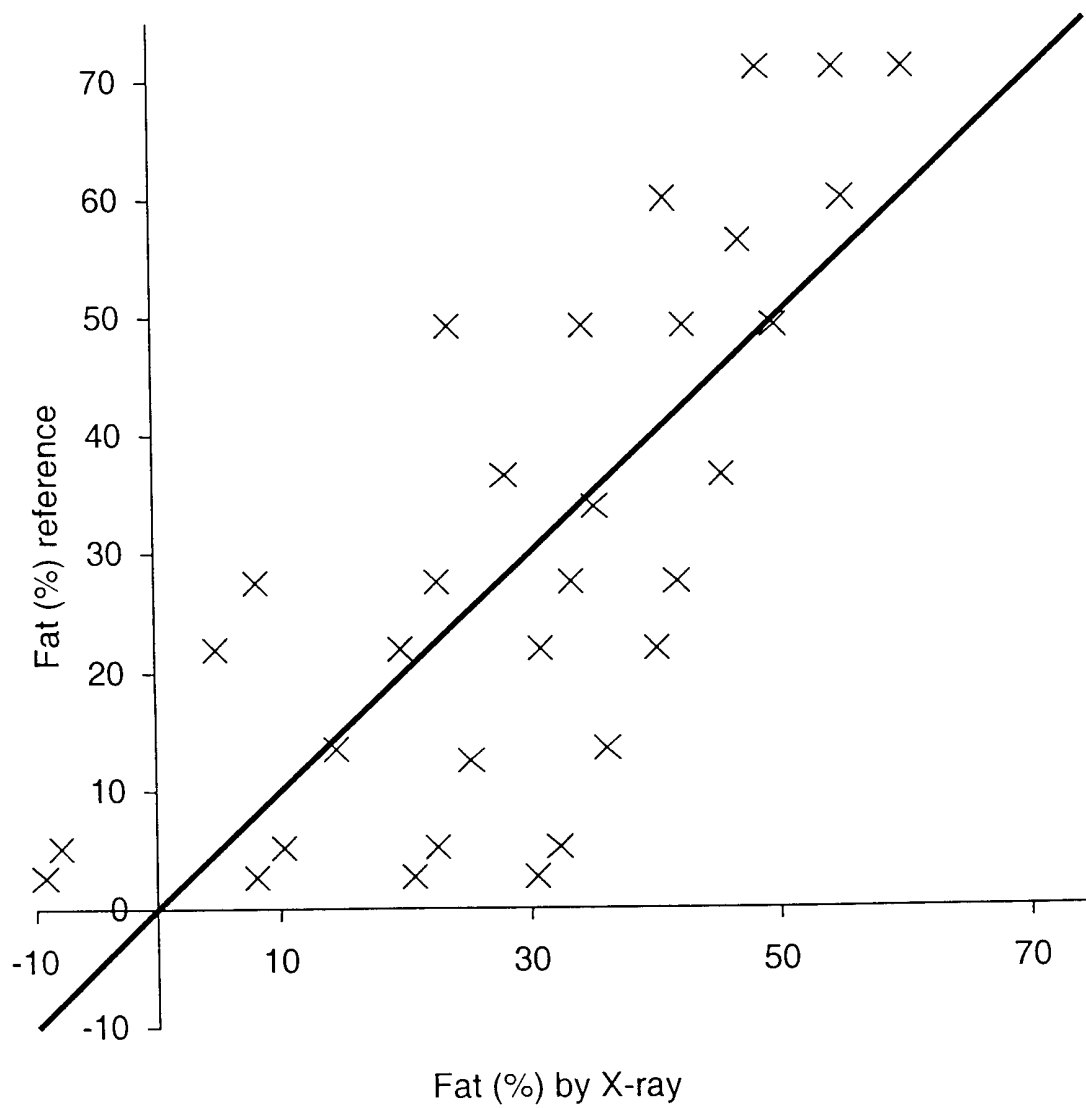


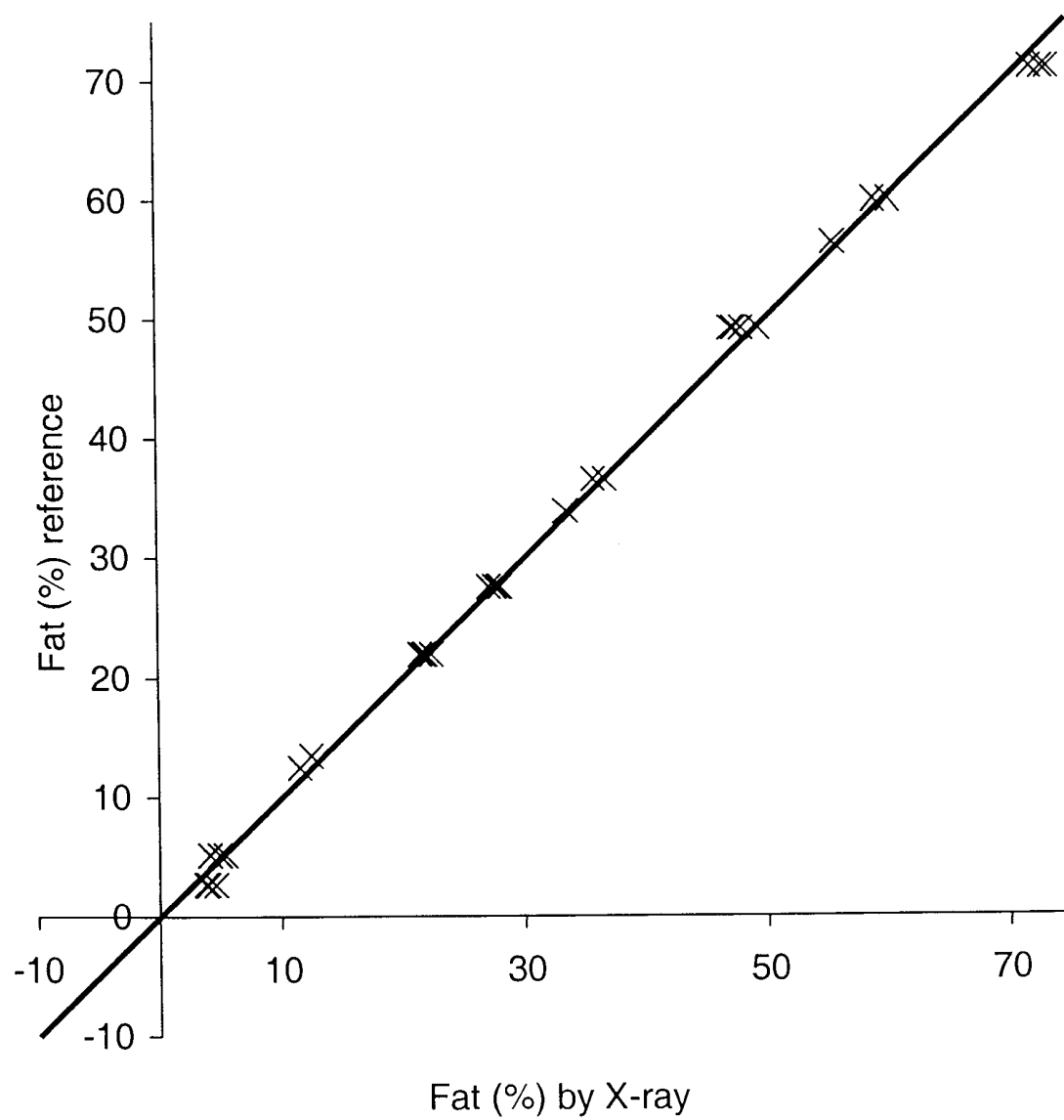
Fig. 3



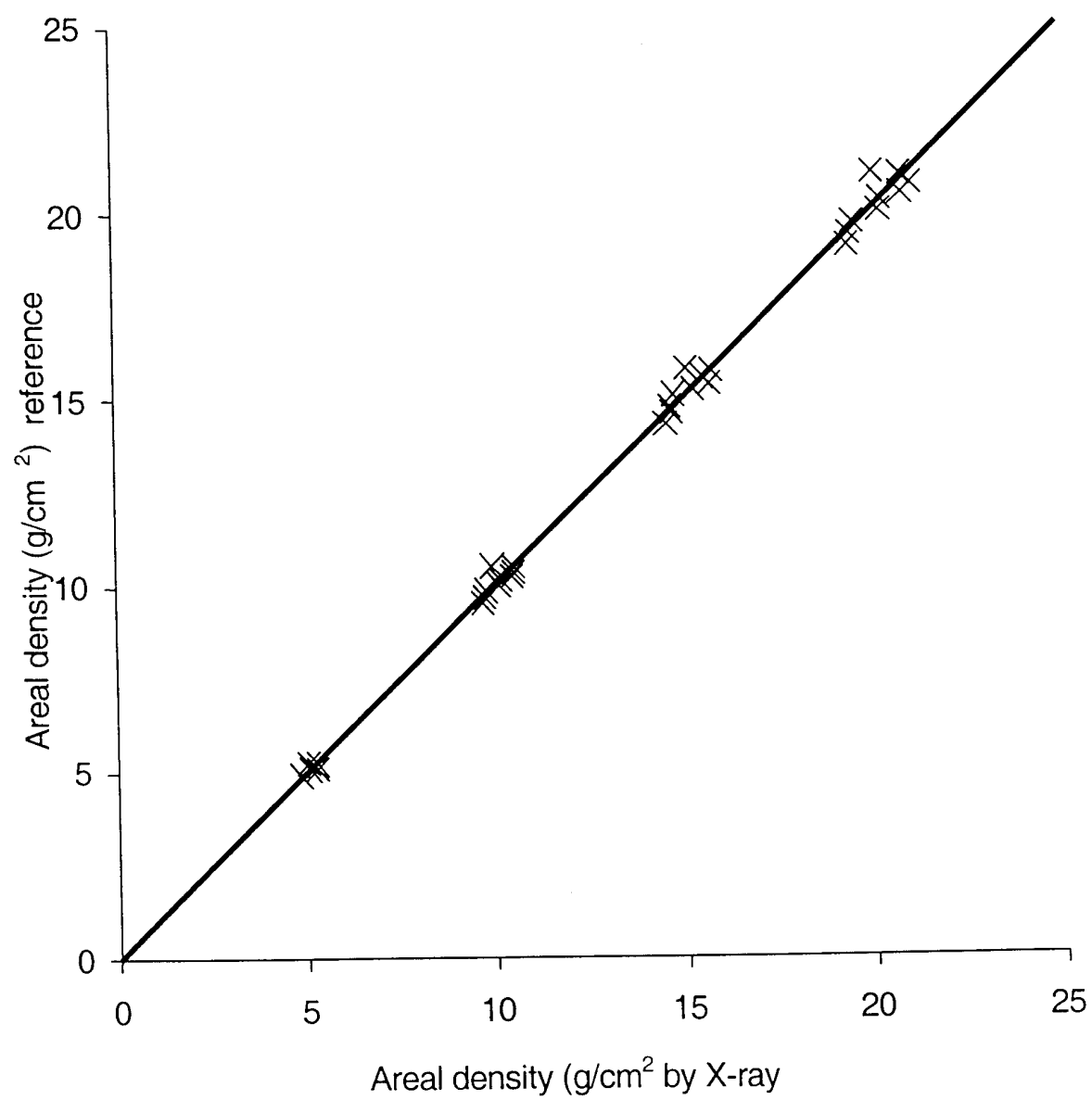
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*Fig. 4*

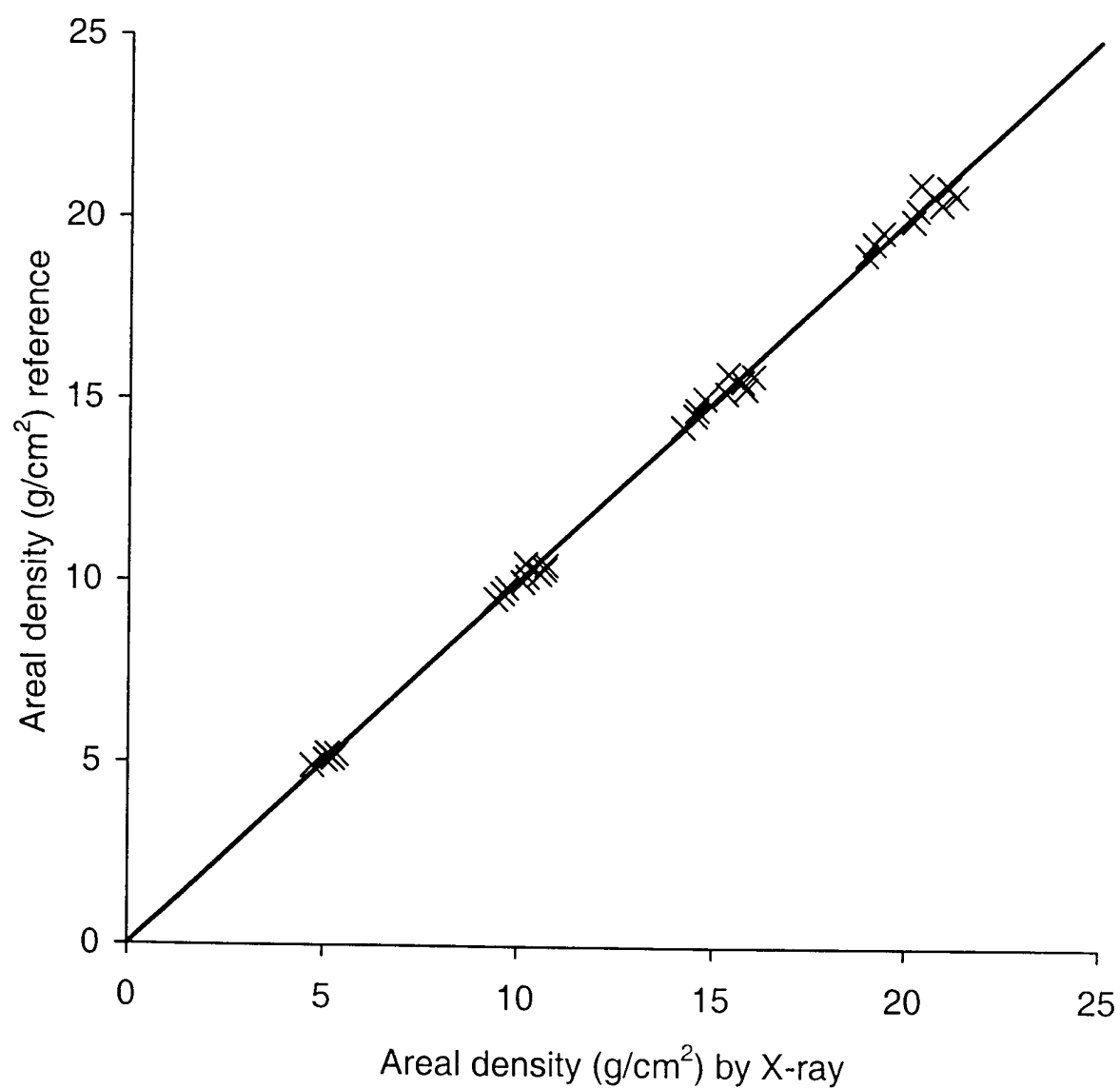
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*Fig. 5*

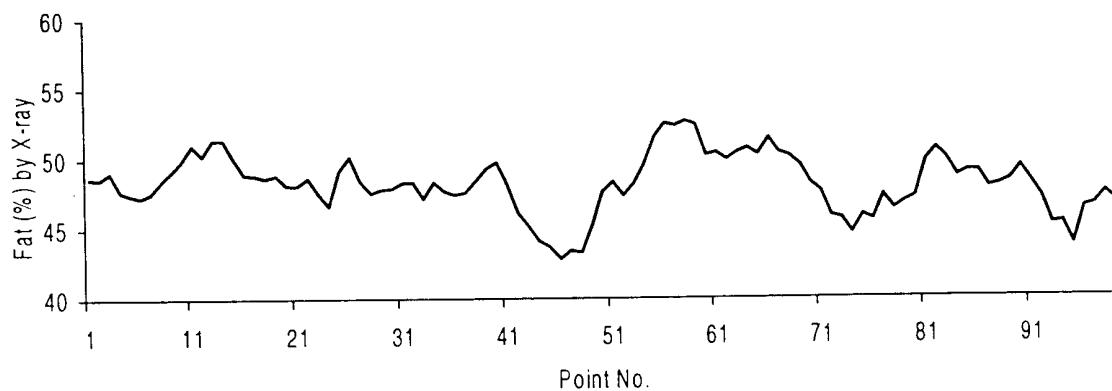
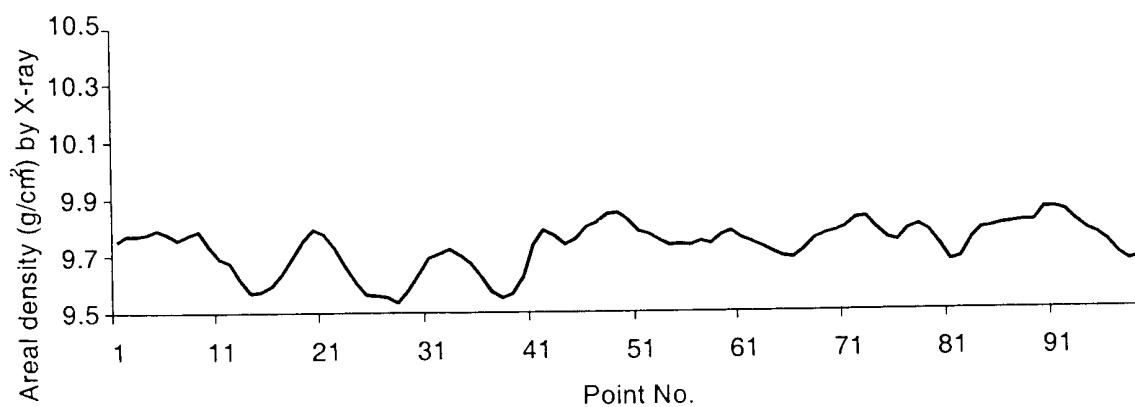
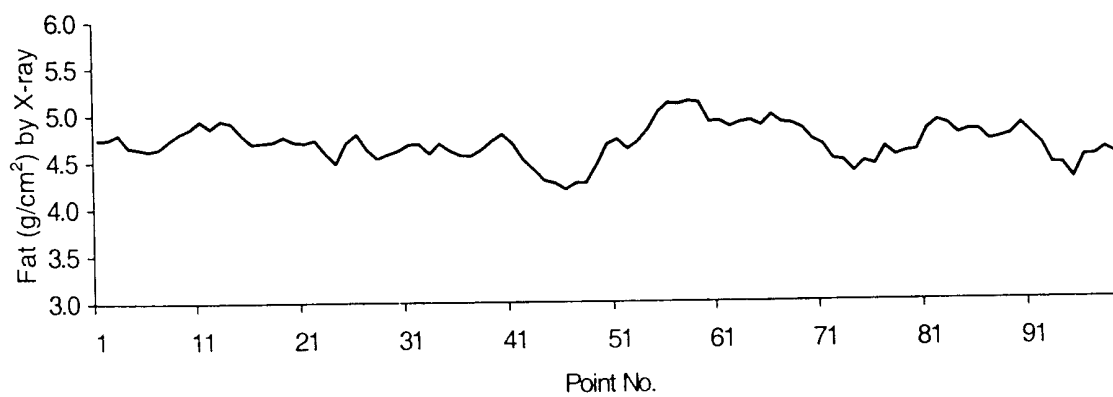
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*Fig. 6*

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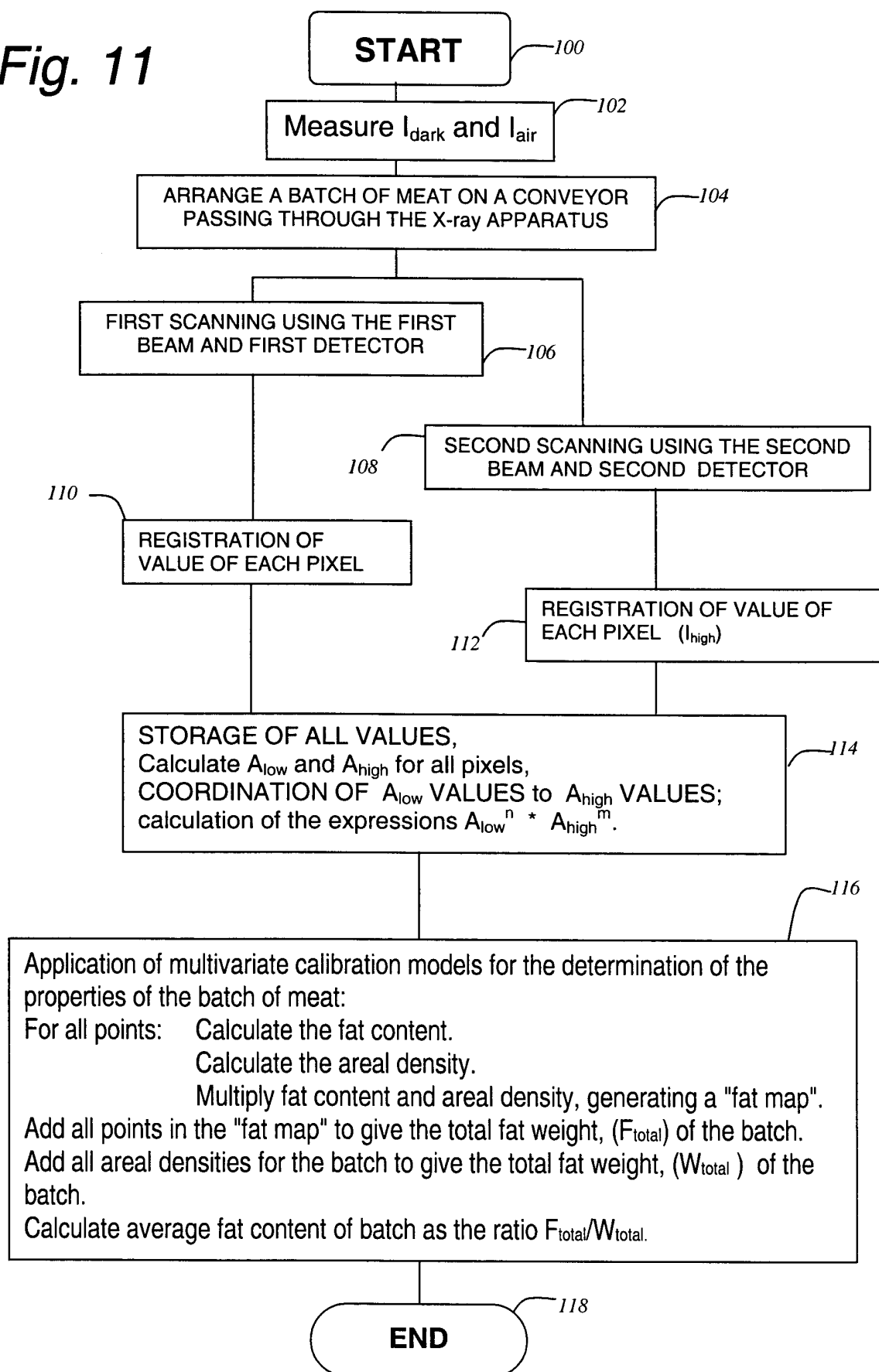
*Fig. 7*

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*Fig. 8**Fig. 9**Fig. 10*

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Fig. 11



10/13



Fig. 12

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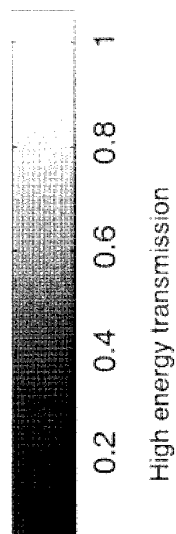
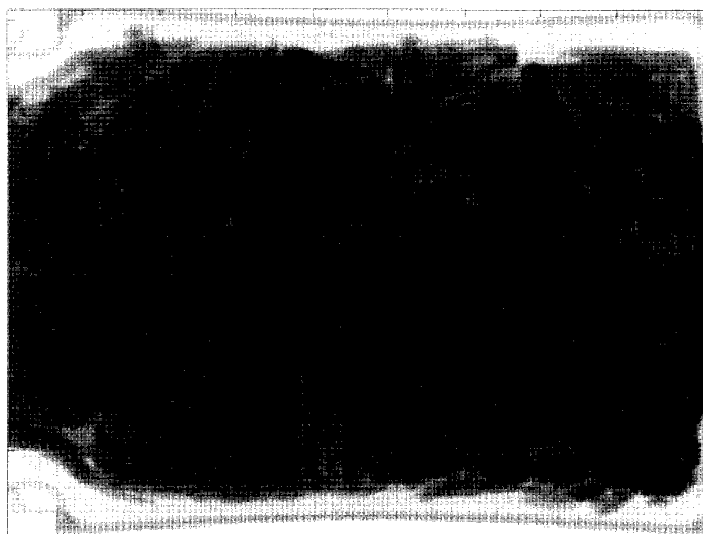


Fig. 14

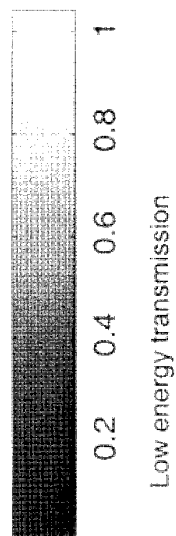
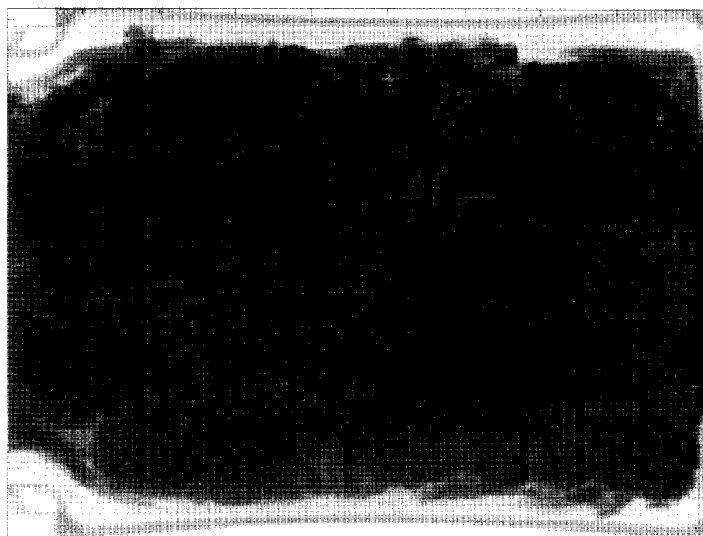
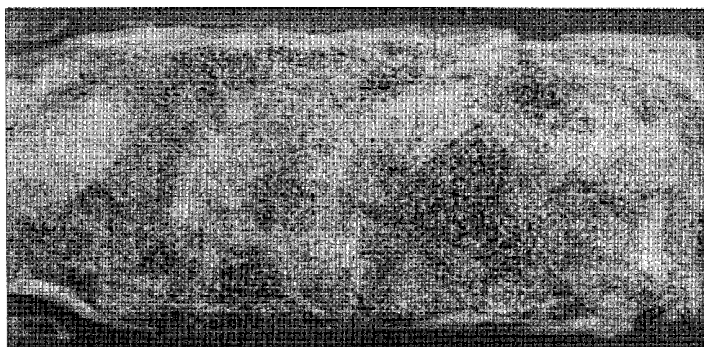


Fig. 13

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-5 0 5 10 15

"Fat map" (g/cm²)

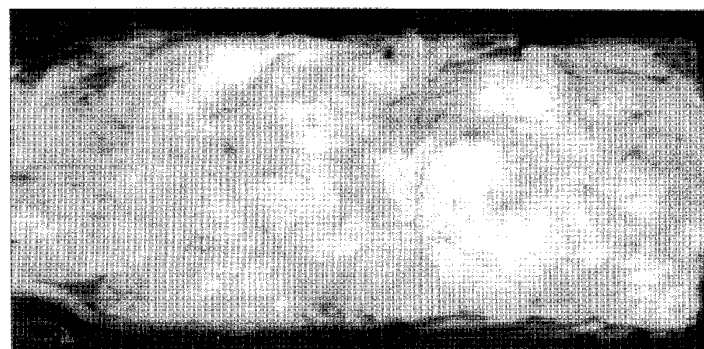
Fig. 17



-100 0 100 200

Fat content (%)

Fig. 16

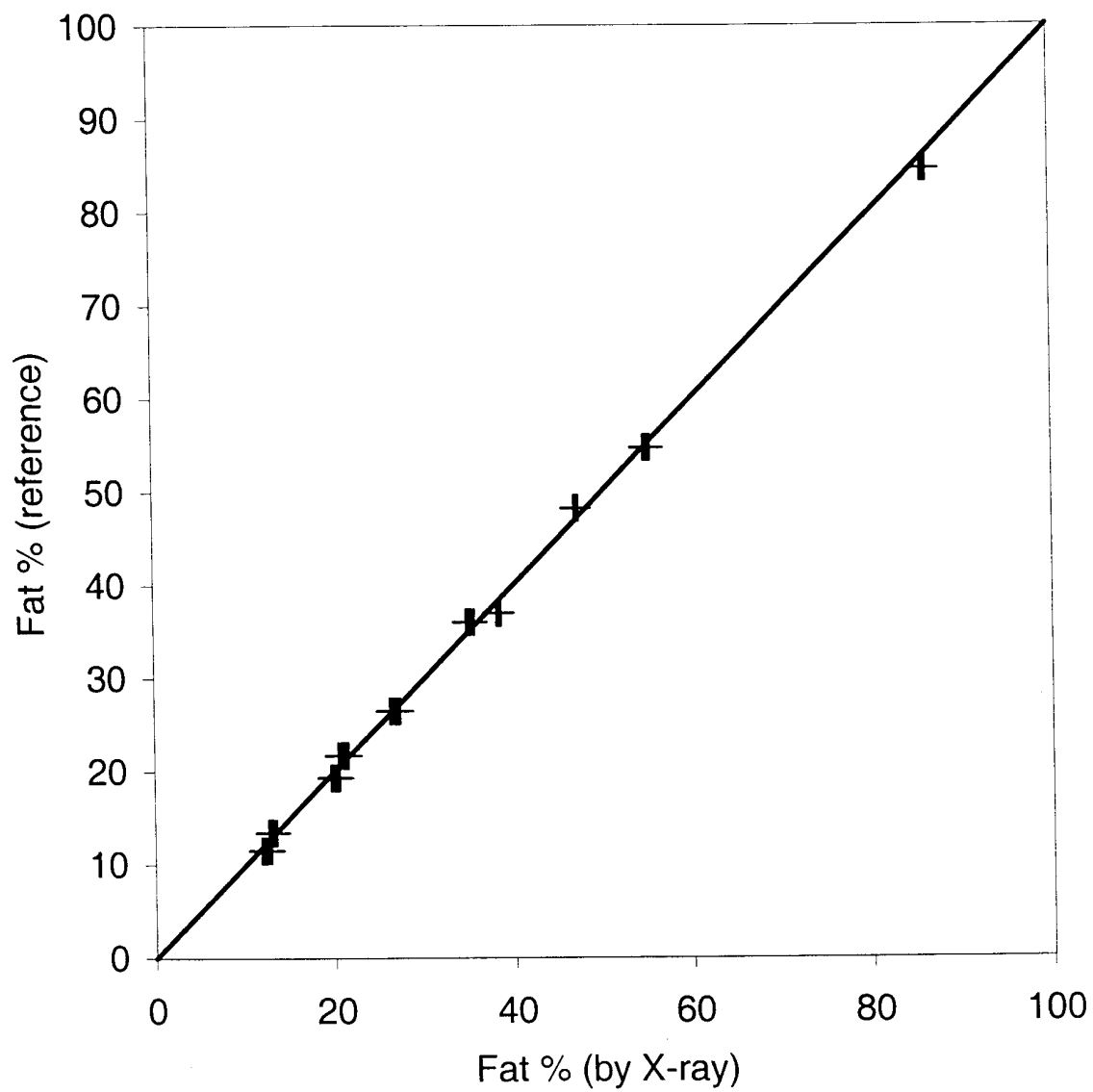


0 5 10 15

Areal density (g/cm²)

Fig. 15

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*Fig. 18*