Use of Near Infrared Spectroscopy in the Meat Industry

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Abstract

The Near Infrared region of the energy spectrum was first discovered by Hershel in the year 1800. The principles of NIR is based on light absorption of specific organic chemical bonds. The absorption at each wavelength is measured and a spectre is obtained. The spectre is then treated mathematically and with the absorption data is converted to absolute units via a calibration.

In the last two decades it has developed dramatically. With the invention of computers and the ability to treat a large amount of data in a very short time the use of NIR for many different purposes has developed very fast. During the last decade with the aid of very powerful PC's the application of NIR technology has become even more widespread. Now or days development of very robust calibrations can be done in a relatively short time with a minimum of resources.

The use of Near Infrared Spectroscopy (NIR) in the Meat industry is relatively new. The first installations were taken into operation in the 80ties. The Meat Industry is often referred to as rather conservative and slow to embrace new technologies, they stay with the old and proven methods.

The first NIR instruments used by the Meat Industry, and most other industries, were multi -purpose build, which means that the sample presentation was not well suited to this particular application, or many other applications for that sake.

As the Meat Industry grows and develops to meet the demands of the modern markets, they realise the need for better control of processes and final products.

From the early 90 ties and onward the demand for "real time" rapid results starts growing, and some suppliers of NIR instruments (and instruments based on other technologies, like X-ray) start to develop and manufacture instrumentation dedicated to the particular needs of the Meat Industry.

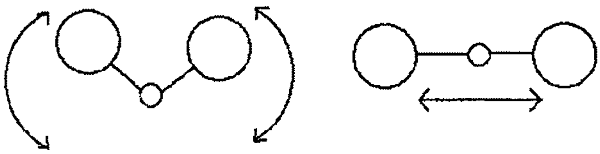
Today it is estimated that there are approximately 2000 rapid instruments placed in the Meat industry world-wide. By far most of these are used as at-line or laboratory installations, but the trend and need is moving towards real on-line or in-line solutions.

NIR is the most cost effective and reproducible analytical procedure available for the twenty first century.

Ⅰ. History of Near Infrared Spectroscopy:

The NIR region of the energy spectrum was first discovered by Hershel in 1800. He discovered by temperature measurements that there is invisible energy beyond the red end of the visible spectrum from sunlight diffracted by a prism. The short -wave NIR region (800~1100 nm) is still called the Hershel region. The modern Near infrared Spectroscopy as we know it , has been established mainly due to the early work of Karl Noris.

Molecular Vibrations have Characteristic Frequencies



Some of the absorbed light energy is used to 'power' these vibrations and is detected as a loss of light.

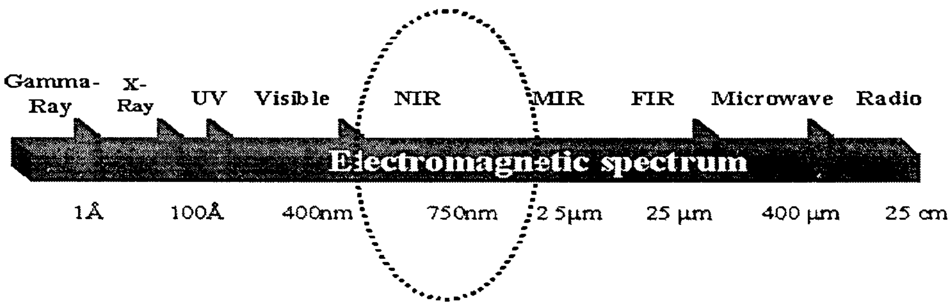
1. Principles of light absorption:

The term absorption is sometimes hard for people to understand. We say that a shirt is blue because it absorbs the blue colour but reflects all other colours. So it is the same with near infrared absorption. Absorption occurs when energy emitted from a source (light bulb) at a frequency that corresponds with the vibration of an NH bond and the energy is absorbed by the bond. When this happens, the radiation at all other wavelengths is reflected. Since each CH, NH, and OH bond has a specific vibrational frequency we can describe the absorption information with three parameters.

These parameters are the location of the information in terms of nanometers, its amplitude by the height of the absorption peak, and the width of the peak describing its intensity. With these three parameters (location, height, and width) all absorption information for a substance can be defined.

Although the absorption of energy is easy to explain in its simplest form, the absorption pattern in the NIR region is extremely complex. Every biological substance contains thousands of CH, OH, and NH molecular bonds. This is because of the complex nature of all the elements and compounds making up every different kind of biological substance. In addition, the information is packed tightly in a tiny region of EMS from 800 to 2500 nm. The information is repeated in an overtone sequence and combination bands of two or more absorptions. Although the NIR spectrum is rich in information, it is highly repetitive, confounded by radiation scatter and surface reflectance as is the visible spectrum, and overlapping peaks. This made the information virtually impossible to understand and use in any practical manner before modern computers appeared in the late 60ties.

The NIR spectrum obtained from a substance is therefore a composite of all the chemical and physical information of the external surface(s). The radiation has very little energy and penetrates only a millimetre or so into the substance depending on the substance's surface composition and structure. By exposing the surface of a plant leaf to NIR radiation, the energy is either scattered, reflected like a mirror, or absorbed by the leaf's chemical bonds. This very complex spectrum describes the physical and chemical composition of the substance.



The NIR spectrum is unique for each and every biological substance. Quantification of this information is the next challenge in making NIR a practical analytical tool.

Ⅱ. Different NIR principles:

Even that most Near infrared instruments consist of the same basic components the accuracy of the instrument can be very different. This is because the accuracy of the instrument is to a certain degree dependent on the placement of the components.

The basic components of the NIR instruments are: a source to generate the necessary NIR radiation, a monochromator or filters to provide a narrow band of wavelengths and a detector to measure the radiation after interaction with the sample. An A/D converter to digitise the analogue signal that is sent to a computer for further calculation. The computer calculates the result by means of a preinstalled calibration equation.

Of the presently available commercial instruments, most differs in the design of the monochromator and the detector.

The placement of the detector depends on whether the instrument will be used for transmittance or reflectance technology.

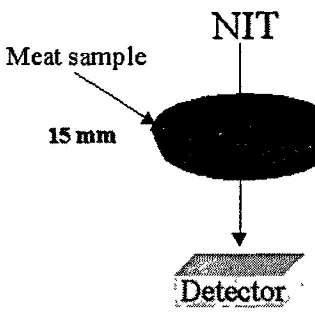
The reflectance measurements are made at wavelengths typically between 1600 and 2500 nm. The infrared light is directed against the surface of the sample. A suitable optical detector measures the energy scattered off the surface. The sample must be very homogeneous as the energy only penetrates 1-to 2 mm of the surface. Hence the results will depend on the surface being representative for the rest of the sample.

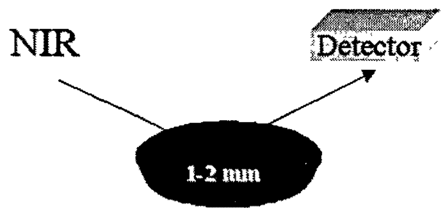
The transmittance technology uses near Infrared energy at somewhat shorter wavelength. This Very Near Infrared energy intersects the surface of the sample. A portion of this energy is transmitted through the sample and exits from the rear of the sample. A detector is used to measure this exiting scatted light. These transmission measurements are typically performed between 750～1100 nm. The obvious advantage of transmission is its ability to measure thick samples. This eliminates the error of an inhomogeneous surface.

As the surface of a meat sample normally is inhomogeneous, NIT near infrared transmission must certainly be used to obtain the best accuracy.

The device for providing the narrow band of light can either be a monochromator or filters. The monochromator consist of a mirror there sends the white light to a moving grating unit which splits the light up into every single wavelength. Each wavelength then one at a time pass' through a slit and enter the sample. By using this technique you will obtain absorbency information from the whole spectra.

When using filters technique then you have chosen the wavelength in the full spectra that gives you the most information. Hence you only get a few information but if you have chosen the right filters then it is more than enough because the rest of the spectra might just generate noise. However if you use the filter technology to analyse an another product than the one the filters have been chosen for then you can see that the accuracy of the filter instrument can be decreased.





Ⅲ. Calibration principles:

The most popular way to use NIR technology is to calibrate it with reference values obtained from a laboratory or some other source. Interpretation of the absorption information is extremely complex and must be related to some known analytical value to be of practical significance. Typically most agriculture and food applications use NIR to predict protein, fat, fibre, and moisture in a material. The quantification is accomplished by obtaining reference values from a laboratory for all samples in the product library.

A number of regression methods are available to make the prediction equation or model. Popular methods are stepwise regression, partial least squares regression, and neural networks. If all samples are used in the library, the calibration equation is referred to as a global calibration. Global calibration equations can be developed either for linear or non linear regression procedures like neural networks. In addition, new procedures are now available to develop local calibrations for each sample-constituent of the product during routine operation.

The most important part of the calibration process is not choosing the regression technique, but developing the database for the product. Two important sources of error must be considered at this point. The first is how accurate is the method, and second, how repeatable is it. Accuracy is the agreement between the reference value and the predicted value from the NIR spectrum. Repeatability is the agreement among subsamples analysed from the same material, or subsamples analysed by different instruments. The errors of accuracy and repeatability determine the usefulness of the analysis.

In general repeatability is almost always very acceptable, but the accuracy is a function of the material, constituents within that material, and the repeatability of the laboratory procedure developing the reference values. To give some insight into what has and is being analysed by this technology, lets look at the applications.

1. NIR applications

The NIR technology is used daily in a vast number of applications around the world. In agriculture the technology provides nutritional analysis of feeding rations for millions of dairy cows. The feed industry serving the poultry and swine industry is using NIR broadly as a reliable analytical method. The analysis of grains by NIR serves as the marketing tool for feed and food supplies. In the food industry the large confectionery companies use NIR to measure their raw materials and finished products. The technology is used by the dairy industry in quality control of butter and cheese. And the meat industry surrounding the fast food business relied heavily on NIR to control the quality of their products. The list goes on and on.

Near infrared analysis is no longer an analytical procedure to be used by universities and research institutions. It is becoming the only analytical procedure that can possible produce information about the composition of feed and food products to provide information for our modern electronic communication system.

Ⅳ. Calibration in the future:

In the future we must expect to see further developments in calibration techniques. Constantly the tools and methods for calibration development are improving.

Fortunately for the users who are not statisticians, methods are now being build into instruments and soft ware so the operators only have to calibrate and run the program without worrying about subtleties of the mathematics.

One new possibility not too far away is the so called Local or Neighbourhood method. With this method a specific calibration for a given product matrix does not exist in the traditional way. The principle builds on a very comprehensive database with known spectra and corresponding reference values, when a new and unknown sample is analysed the calibration software will seek through the entire database and pick the spectra that are alike or very similar, it will then build a PLS calibration from these spectra and their corresponding reference values and predict the new unknown sample.

It is envisaged that these very comprehensive databases could be held centrally in computer mainframes of suppliers of NIR equipment or alike. They would then constantly update the databases and maintain their performance.

The users of NIR equipment would obtain a spectra of the unknown sample on their instrument, send the spectra via the Internet to the holder of the database and get a prediction result back within a very short time. It would be possible to charge the users of the instrument per prediction obtained from the database.

Ⅴ. Meat Industry needs:

The meat industry in many countries is making large efforts to optimise and modernise its production. Quality and quality assurance e.g. enclosed in an ISO 9000 certificate, are becoming major issues' as the consumers become more and more demanding.

Of basic importance to the manufacture of all process meats is selection of proper raw materials. Quality of these meats as determined by their chemical and microbiological status should be high, for it is certain that a finished product can never be of higher quality that the ingredients it contains.

When producing for example smoked meats, the concern is only with primal cuts. However, when manufacturing sausage, hamburgers and canned meats, the pork or beef trimmings for example are mainly coming from two sources, from boned primal cuts and from trimmings obtained during preparation of primal cuts for curing or merchandised as fresh pork, beef steaks, fillets etc. Therefore the composition of the trimmings varies quite a lot and even as the trimmings are sold according to fat categories it is important to check the quality of the trimmings.

Trimmings are normally divided into lean and fat trimmings. Lean pork trimmings consist in most countries of special lean 80% and extra lean 90 %. Fat trim consists of regular and 50% trimmings. Regular pork trim contains 55~60 % fat, whereas 50% trim contains 45~55% fat. So the trimmings the manufacture buys for being 50 % fat might indeed be 55 % fat. The same principle applies to beef trimmings.

So if the producer are to mix a 50% fat trim with special lean pork trimmings in a proportion of 1to 1 he might end up with a product that contains either 32.5% fat or 37.5 % fat and that can be very critical for the end product if it varies that much from batch to batch.

In Europe the consumers are very concerned about the quality of the meat product, therefore the retailer through whom most of the meat products are sold, are forced to set very strict demands to their meat suppliers.

Therefore it can be very beneficial to check the raw material before starting the process, further it is becoming more common for retailers to label many meat products with a fairly narrow fat range. In order to ensure the products meet the labelling a fat analysis during processing must take place. NIR is one very suitable technology for this, since it is fast reliable and accurate.

Besides aspects of product quality of course production costs play the decisive role. Therefore the main objective in this regard is the monitoring of the production process and early detection and correction of mistakes.

Any manufacturing process is a dynamic system. Incoming raw material is subject to a series of production stages before the manufacture of the finish product can be completed.

Ⅵ. Application of NIR technology in the Meat industry:

If we look on an emulsified sausage the material has to pass through 12 steps before the sausage is ready to be shipped out.

[Select ingredients] – [Grind] – [Mix] – [Chop or emulsify] – [Stuff] – [Link or tie] → [ ]

– [Smoke] – [cook] – [Shower] – [Chill] – [Peel or slice] → [Package]

An important concept to recognise is that the process is a continuous sequence of events in which each step is an integral part of the whole, thus it is not practical to consider any one step separately or to assign more importance to one step than to another. Each step in its proper sequence is important to a successful operation.

The mode of operation of the process for the product is determined by a number of related, and often competing factors. These include the cost efficiency of continuous operation, the availability of a process line used for the manufacture of other products and demands of the marketplace.

The arrival of raw material, without which there can be no finial product, is itself dependent on variables such as need, availability, and actions taken by the supplies. To further complicate the situation delays or malfunctions during any stages of production can course discontinuities in production schedules and increase production costs.

The condition of the product at all critical stages of the process should be known in order to ensure the production of an acceptable product in the most efficient manner possible. This is usually accomplished by monitoring physical and or chemical characteristics of the product. The information that is obtained can then be used to change the process in order to keep the various product parameters in acceptable limits.

For example, if analytical analysis are performed only on the final product, the discovery of an unacceptable product e.g. emulsified sausages with fat caps indicates that the process is out of control, but little or no information concerning the specific portion of the process that is at fault is provided. Without this information, the process cannot be easily corrected. In this case it could be four different step there is out of order. It could be too little lean meat, which means that the connective tissue protein ratio is too high, or it could be due to over chopping, the surface of the fat becomes too big for the amount of protein or it could be due to under stuffing. The pressure is too low and the light fat flows up to the top of the sausage. It could also be due to too rapid heating where the protein coagulates too fast. So by only analysing the final product you obtain an indication of an error but not where it has happen in production flow and it is also too late to correct it so often the product is wasted. The waste of costly materials and manufacturing cost for an out-of-specification product are both very expensive.

Unfortunately, simple monitoring of certain quality parameters by various analytical methods will not result in automatic improvement of process efficiency. It is also necessary that the required analytical results be timely and relatively accurate. Consider the relationship between extra manufacturing costs and the interval of time between the sampling of the process and the reporting of the analytical results.

If the process at the point at which it is monitored for example at the mixing step is slow relative to the interval between analytical results, corrections to the process can be made, with minimal waste of material, only slightly higher manufacturing expense, and minor delays in the production schedule. If, on the other hand the process is fast relative to that interval - and for most wet-chemistry laboratory methods it is - large quantities of meat can be lost, significantly higher costs, resulting from the manufacture of an unacceptable product, can be expected, and there may be considerable production delays.

The usefulness of an analytical method does not depend only on how rapid it can provide the relevant information; reasonably good agreement between the numerical values obtained from the analysis and the physical or chemical parameters that are being monitored is also necessary.

Appropriate technologies for monitoring the process must meet several criteria including accuracy, speed, reliability, cost, adaptability to the environment, space requirement and payback to the meat manufacture.

Near infrared technology has emerged fast in the recent years since it is able to meet most of the mention criteria. It is certainly an alternative to the slower and more laborious wet-chemistry laboratory methods.

The NIR instruments are adapting more and more to the environment that they are to be placed in. In the beginning nearly all instruments were designed for laboratory use only. The trouble was that the environment in the meat plant is very cold and wet. The instruments were often operated by means of a computer and only the industrial computers were able to work under these hard circumstances. These computers were very expensive and the instrument cost became very high.

Today as the development of computers is rapidly growing the prices for last year technology drops drastically. Hence it is now possible to produce Near infrared instrument that either uses an industrial computer at a reasonable price or to build in a microprocessor in the Near infrared instrument that is big enough to handle the operation.

Today NIR instruments can be seen all over Europe and North America as both “at line” instruments or “on-line” in the process often placed on the mixer, next to the mixer or of course still in the laboratories.

It is for certain that the trend is moving towards on-line or in-line analysis as the industry is under pressure to be extremely efficient and utilise production capacity optimally to justify the investments in production lines as well as workforce.

Ⅶ. Examples of economic benefits using NIR:

1. Example 1:

The meat producer produces15 tonnes of sausages per day- 3,500 T/Y. He buys fat- and meat trimmings from various slaughterhouses, he doesn't buy a specific type of meat trimmings but purchases what ever is the best value at a given time. This means that the fat content of the trimmings he buys varies significantly. Further the processor knows that after he has mixed his own meat material blend for the production, the fat content of this standardised blend must be max. 40% fat. He knows by experience this is what his recipe can hold, if fat percentage is higher there is a big risk of fat cook-out on the surface of the sausages, and the sausages will be rejected by his customers.

On the other hand, for economic reasons it's important to his overall profits to be as close to the 40% fat as possible, since fat is a lot cheaper than lean meat.

Let's assume his present accuracy is 2%, then he is aiming at 38% fat to fulfil the max 40%.

On average he pays: Fat trimmings 0.5 $US per kg.
Lean Trimmings 2.0 $US per kg

This means that per year he can save 78,750 $US in raw material just by analyse the material with an instrument with a 1.5 % better accuracy. So as you can see just a little improvement of the accuracy play an important roll as well.

2. Example 2:

A meatpacker supplies a chain of supermarkets with minced beef. On the retail packaging is declared max. 15% fat.

However, the meatpacker is analysing on an old and not very accurate instrument(+/− 1.5%).
He is supplying 4 tonnes per day = 1000 tonnes per year - of this product to the supermarkets.

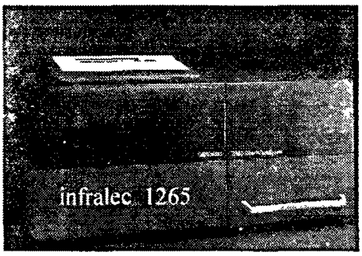
The minced beef is mixed from two sources of meat:

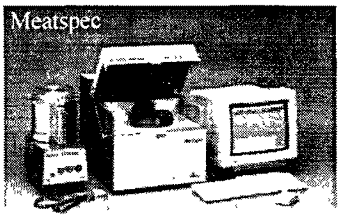
Lean beef (8~10% fat)	3.50 $/kg
Beef fat	0.50 $/kg

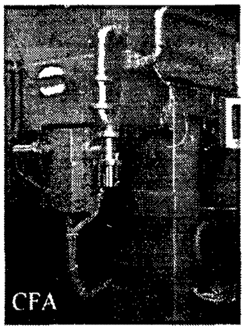
The Infratec 1265 has an accuracy of +/− 0.5% versus his "old" instrument with +/−1.5%. This means that he can now supply minced beef with 14.5% fat and still guarantee max. 15% fat, versus 13.5% with the old instrument.

Calculation: (1,000,000 kgs/y × 3.0 $/kg × (1.5−1)%) = 30,000 $ cost saving per year

Ⅷ. Foss product range :







CFA & Meatspec

Technology

- vNIT-wavelength 825~1075
- Filter technolgoy
- Measurement every 25 nm

Infratec 1265

Technology

- vNIT - wavelength 850~1050
- Monochromator
- Measurement every 2 nm

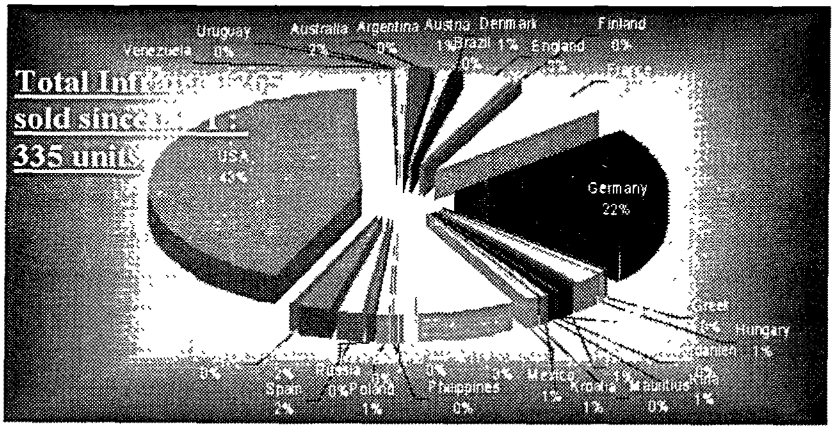
Ⅸ. Future outlook:

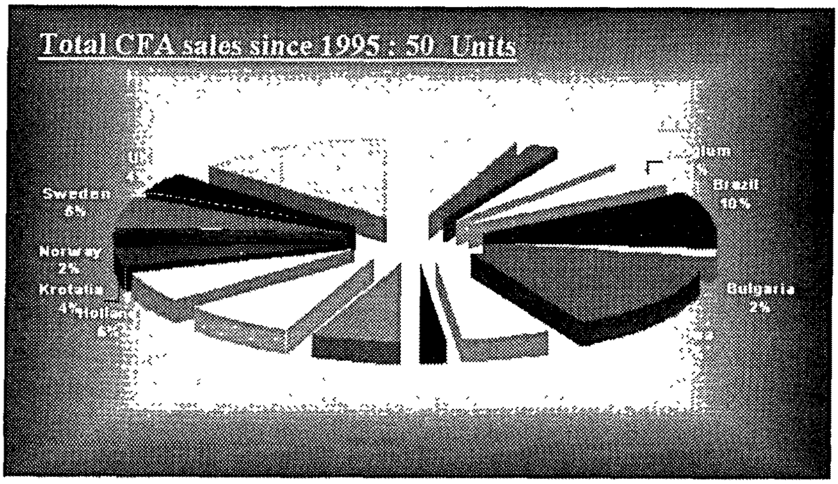
As mentioned earlier in this paper the trend in the industry is moving towards on-line (or in-line) analysis. In many markets and industries the production monitoring laboratories play a less important role in the every day control of processes and production as well as in controlling final products.

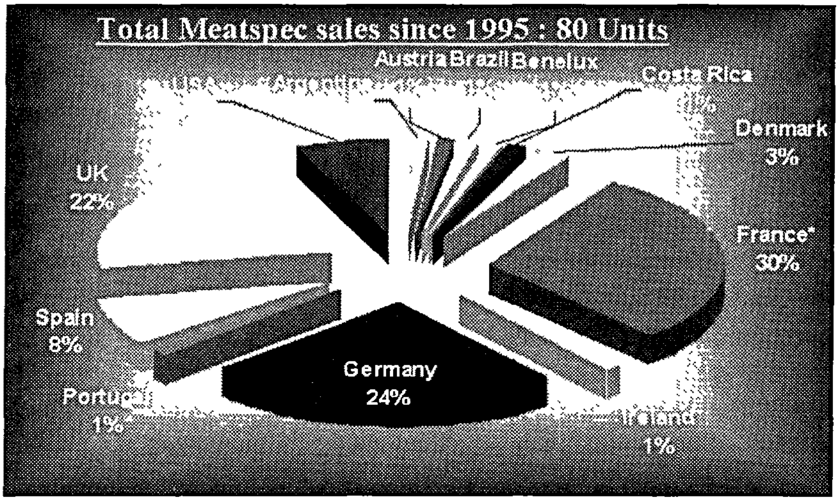
In the R&D project portfolio of Foss, on-line equipment plays an even more important role. Market studies conclude that already now and even more in the future on-line analysis is the area where most investments and therefore growth is to be expected.

Foss - First in Food Analysis - is constantly seeking to stay first in its field, and in the future other technologies than NIR will belong to our core competencies.

Ⅹ. Market overview:







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