Concentration Measurements with low energy gamma rays

Radiometric density measurements have been used for years in many industrial applications.

This measuring method does not require any installations in the pipeline; therefore, it can be employed universally and it features a high operational safety even in difficult applications.
Widely known are measuring systems using the Cs-137 isotope for density measurements on pipelines from 15 mm up to approx. 800 - 1000 mm diameter. Moreover, this method may also be used for process monitoring in vessels. The use of other isotopes emitting low-energy gamma radiation offers new possibilities for the on-line measurement of concentrations.

1. The Principle of Measurement

The measurement utilizes the principle that gamma radiation is weakened as it passes through the product to be measured. The measuring system comprises:

a)b) radioactive source with shielding container
c) detector
d) evaluation unit
e) clamping device

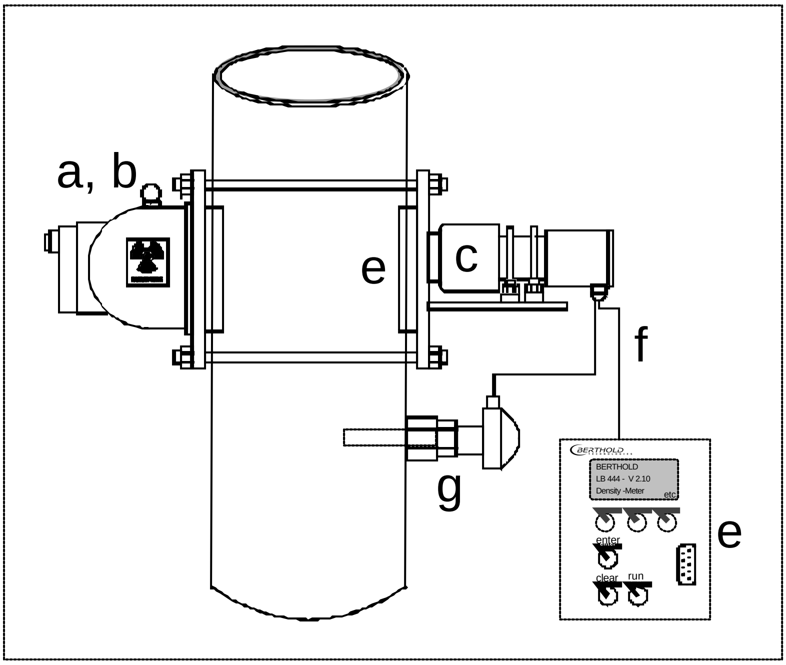

Fig. 1: Setup of a radiometric measuring system with Cs-137 source

The radioactive source is installed in a shielding which permits the radiation to exit only in the direction of the measuring pipe or the detector, respectively. The residual radiation picked up by the detector is measured and converted into an electrical signal (pulses). These pulses together with other information are transmitted to the evaluation unit and there converted into a current signal 0 - 20 mA or 4-20 mA.

Berthold Technologies GmbH & Co. KG
Calmbacher Str. 22
D-75323 Bad Wildbad
Phone: ++49 (0)7081/177-0
Fax ++49 (0)7081/177-100
Industry@BertholdTech.com
http://www.BertholdTech.com

The radiation is attenuated according to the familiar law of absorption.

$$I = I_0 * e^{-\mu*\rho*d} \qquad (1)$$

Io	=	emitted radiation intensity
I	=	radiation picked up by the detector
ρ	=	density of the absorber in g/cm3
µ	=	absorption coefficient
d	=	thickness of the absorber in cm

Since the wall thickness of the pipeline and its internal diameter (measuring path d) may be considered constant, the signal picked up by the detector is only dependent upon the density r of the product. For the intensity change it holds:

$$I_1 / I_2 = e^{\mu*\rho*d} \qquad (2)$$

I1/I2	=	intensity ratio for Δρ
Δρ	=	density change of the product

For two-substance mixtures this formula is valid only as long as the absorption coefficient m is the same for both components. If this is not the case, the following equation has to be inserted:

$$I1/I2 = e^a \qquad (3)$$

$$a=\{[c_2 \cdot \mu_1 + (1-c_2) \cdot \mu_2] \cdot \rho_2 - [c_1 \cdot \mu_1 + (1 - c_1) \cdot \mu_2)] \cdot \rho_1\} \cdot d$$

μ_1, μ_2	=	absorption coefficients for components 1 and 2
c_1, c_2	=	concentration in weight percent/100

Several factors are therefore responsible for the intensity change as a result of the change in concentration.

a) Density change

The density of a two-substance mixture (e.g. water/HCl) is defined by the concentration of both substances. With rising HCl concentration, the density increases, because water is substituted by HCl which has a higher density than water.

b) Absorption coefficients

With different absorption coefficients for both components, an additional factor will affect the density.

c) Measuring path

The measuring path is a constant factor. The greater it is, the greater the intensity change with otherwise equal conditions.

The following alternatives are conceivable for two-substance mixtures:

a) The component with the higher density has a greater absorption coefficient. In this case both influence parameters are added up: the intensity change will be particularly significant and therefore the measuring effect and the measuring accuracy will be excellent.

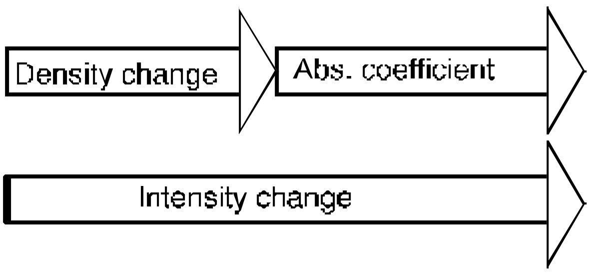

*Fig. 2: The density **and** absorption coefficient of the 2nd component is larger than those of the 1st component: large intensity change*

The same is true when one component has a lower density and a lower absorption coefficient. In this case, both effects are also added up.

b) The densities of both components are the same, but the absorption coefficients differ. This configuration, which is possible in theory, but is hardly ever encountered in practice, shows, however, that the intensity may change even though the density is constant. The greater the difference between both absorption coefficients, the greater the intensity change.

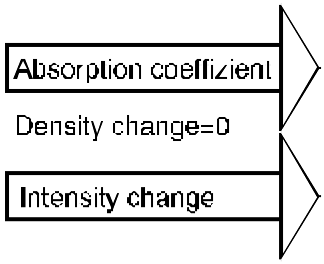

Fig. 3: Even when the density of both components is the same, but the absorption coefficients differ, there will still be a measuring effect.

c) When the density of the second component is greater, its absorption coefficient, however, smaller than that of the first component, both effects cancel each other out. In this case, a density change results only in a minor or, possibly, no intensity change at all. Mixtures of this kind are not very well suited for measurements. However, this constellation has a positive effect when impurities with fluctuating concentration occur and the substance causing the problem shows such a behaviour. In this case, the impurity has only a minor influence on the result of the measurement.

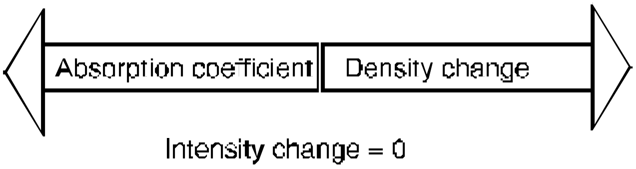

Fig. 4: With opposed behavior of density and absorption coefficient one will only get a minor or no intensity change at all.

2. Radioactive Sources

Only so-called encapsulated sources are used as radioactive sources for industrial measurements. The actual radioactive substance is tightly encapsulated in metal capsules. Usually, Special Form Certificates (= highly safe version) are available for these capsules.

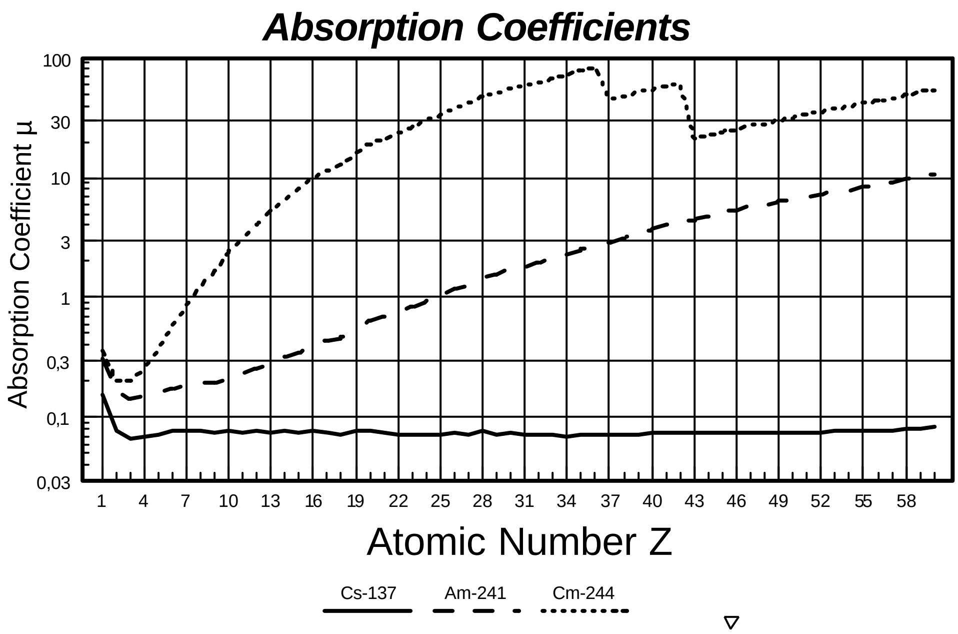

Fig. 6: Absorption coefficients for gamma radiation emitted by the isotopes Cs-137, Am-241 and Cm-244

Fig. 6 shows the absorption coefficients for the gamma radiation emitted by both isotopes. For comparison's sake, the Cs-137 curve is also included. One can easily see that the absorption coefficients for Cs-137 are virtually constant with substances which are usually to be measured. With Am-241 and Cm-244, the absorption coefficient rises significantly with the atomic number. This means that particularly for the measurement of mixtures where one component includes elements with a high atomic number one may get high intensity changes and thus high measuring accuracies.

3. Measuring Paths

Since low-energy gamma radiation is nearly completely absorbed by a few millimeters of steel, no measurements can be carried out on steel pipes with larger diameters. On the other hand, this keeps the costs for shielding the radiation to a minimum, so that the shielding on the source side requires only little space, and the radiation, on the other hand, is largely absorbed by the detector and the detector housing. Thus, the entire unit can be set up rather compact.

Measuring Path for Am-241-Source

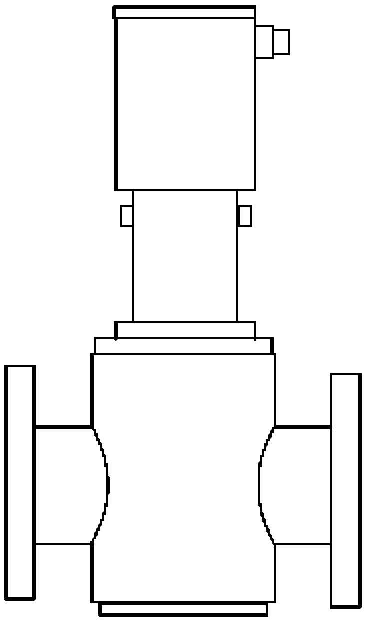

Fig. 7: Measuring path with Am-241 source

The measuring path consists of a 250 mm long DN 65 stainless steel pipe, provided with a flange on both sides. If necessary, the pipe piece may be provided with a PTFE or rubber lining. The detector is installed to one side of this pipe piece, and the radiation source with the bracket to the other side. All parts are housed in a sealed stainless steel housing (protection class IP 65). The detector is explosion-proof according to EEx de IIc T6.

b) Measuring Path with Cm-244 Source

The measuring path is of similar design as the one described above. A polypropylene pipe with an internal diameter of 51 mm serves as measuring pipe. The detector is also explosion-proof according to EEx de IIc T 6.

4. Measuring Accuracies

For radiometric measurements one should keep in mind that the radiation required for a measurement is emitted as a consequence of nuclear transformation processes. Therefore, it is not emitted regularly, but is subject to statistical laws. To reduce the statistical variations, the evaluation unit calculates a sliding average. This sliding average is subject to a time constant

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(attenuation). The measuring error in radiometric measurements is usually given as 2σ standard deviation which is calculated as follows:

$$2\sigma = \frac{2 * M}{\sqrt{2 * n * \tau} * \ln \frac{I_1}{I_2}} \qquad (3)$$

n = count rate
τ = time constant
M = measuring value change (concentration change) for I_1 / I_2
I_1 / I_2 = s. formula (2)

This equation shows that the measuring error decreases, the greater the intensity ratio I_1 / I_2
for a given concentration change. High absorption coefficients have a very positive effect.

5. Application Examples

The method described allows a variety of interesting application. Some of the major ones will be discussed below.

a)Applications with Am-241 measuring path

Concentration measurement of water-HCl mixture.
The high absorption coefficient of chlorine has a favorable effect. One uses a measuring path with PTFE lining. Accuracies up to ± 0.1 g/l = 0.02 % HCl can be reached.

Measurements of salt solution with impurities caused by hydrocarbons
Again, a measuring path with PTFE lining is used. Positive is that the absorption coefficient of the impurities, whose shares fluctuate, is lower than that of NaCl. Thus, the measuring error caused by the impurities will be reduced significantly.

Concentration measurement of Titan dioxide (TiO2) in a mixture of water and ethylene glycol.
In this case, the ratio of water and ethylene glycol may vary. Thus, the density of the carrier liquid will also vary. Since the absorption coefficient of TiO2 is far higher than that of water or ethylene glycol, these variations have only a minor effect on the measuring result.

Measuring of the tin content of electroplating solution
In this case is also the absorption coefficient of the component to be measured, the tin, approx. 6 times higher then the absorption coefficient of the major other component, the iron. And its even much more higher than the absorption coefficient the acids. By this the this the influence of the fluctuation of the other components is very low. At an installed system the accuracy reached is ± 0.1 g tin /l.

b) Measurement with Cm-244 Measuring Path

Such a measuring path is used for the determination of the filling material retention in a paper machine. Paper essentially consists of cellulose fibers and filling materials ($CaCO_3$) as well as small shares of binding agents. The measuring method is preferably used to measure the filling material. A fluctuating share of cellulose fibers hardly affects the measuring result, since the density of the fibers is greater than that of the carrier liquid (water), the absorption coefficient, however, lies below that of water (see Fig. 5). The results are plotted in Fig. 8. The achieved measuring accuracy (1σ fluctuation) is around _ ± 0.02 % $CaCO_3$.

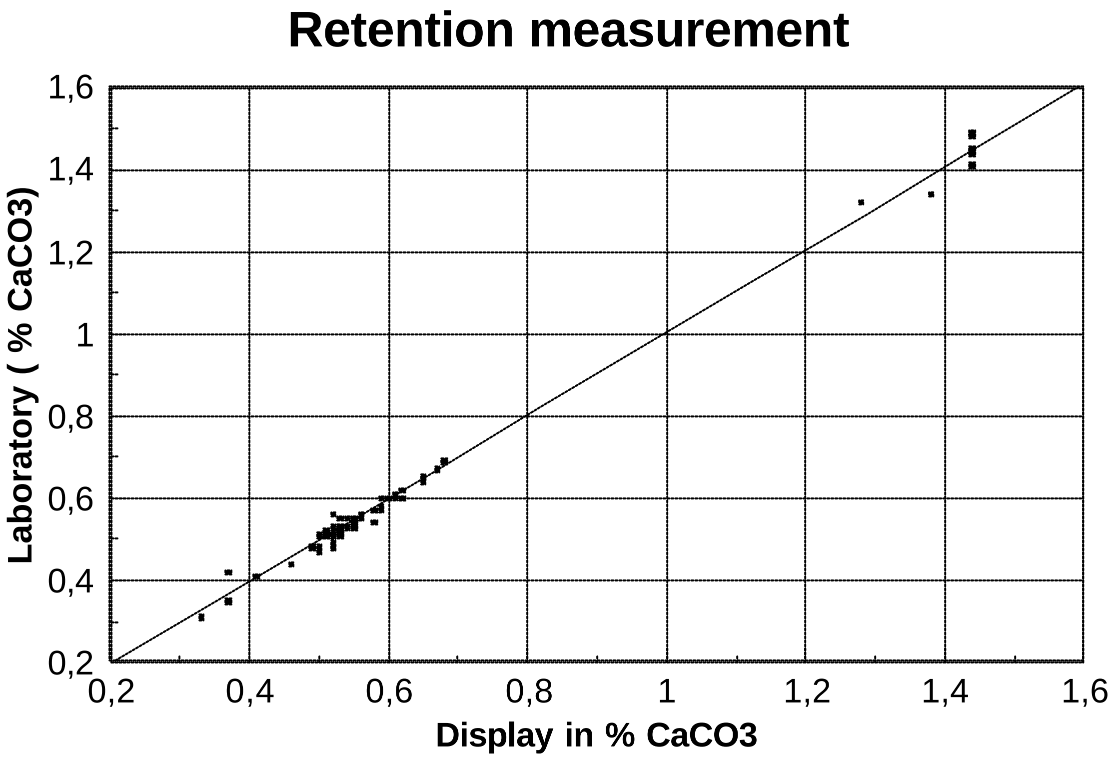

Fig. 8: Retention measurement

Conclusion

Radiometric concentration measurements working with low-energy gamma radiation offer interesting alternatives, particularly when components with high atomic number are to be determined. The measurements are independent of flow velocity, particle size, color, etc. of the product to be measured. The influence of impurities on the measuring result is largely suppressed, depending on their composition.