COMPUTERIZED CONTROL AND SIGNAL PROCESSING FOR INFRARED ANALYZERS

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I. INTRODUCTION

Most gases exhibit a tendency to absorb infrared energy at specific wavelengths. This phenomena has led to the widespread use of infrared absorption techniques for industrial gas analysis. Infrared analysis, however, has enjoyed limited application in the stack monitoring industry because of interferences caused by coexisting gases and lack of sensitivity for measurement of low concentrations. Many improvements have been made in infrared analyzers over the past 20 years and recently the implementation of computer processing of complex infrared analyzer signals has resulted in stack monitoring performance comparable to the best alternative reference methods. This paper will discuss the background of infrared analysis in the stack monitoring industry, improvements in basic measurement techniques, and the use of microprocessors to achieve state of the art performance.

II. BACKGROUND

Figure 1 is a comparison of a popular chemiluminescent NOx device to an equivalent infrared device. In a comparative sense the infrared analyzers are simple, robust and versatile but that ability to measure many gases is a severely limiting factor in applications such as flue gas monitoring. The most common problem lies with interferences caused by water vapor and CO2 that absorb energy at many locations in the infrared spectrum. Since they both are present at high concentrations in flue gas it should be obvious that there is the possibility for a condition that is commonly referred to as interference, cross-sensitivity, or cross-talk (This means that the presence of gases not being measured may cause changes in the measurement of interest).

The ability to measure one gas and ignore the others has been the goal of most infrared instrument developers but to date this has not been realized. Most state of the art instruments now can provide an interference rejection ratio of greater than 1,000 to 1 for most gases but when the measuring range is 0-50 parts per million (PPM) and the interfering gases are changing by as much as 20,000 PPM there may be a large error induced. There are ways to make that interference rejection ratio better and that has been a major improvement in the last two decades.

A. Luft Detector

Figure 2 is a diagram of a Luft Detector which was first developed in the 1950's and offered increased selectivity. Two pulsed infrared beams are generated and are allowed to enter a dual chambered detector, both sides of which are charged with a pure concentration of the gas to be measured. The detector chambers are separated by a diaphragm that will move in response to pressure differences. One of the two beams passes through a reference cell which is normally filled with a non-absorbing gas such as air. The other cell filled with sample gas may contain some of the gas of interest which will diminish the energy available for absorption in the sample side of the detector. The resulting imbalance, more energy entering the reference side of the detector than the sample side, will increase the pressure on the reference side causing the diaphragm to move...the greater the energy lost in the sample cell the greater the movement. The diaphragm is electrically part of a variable capacitor that controls the frequency of an oscillator circuit. As the diaphragm moves the frequency of the oscillator changes, thus variations of the measured gas result in frequency modulation of the oscillator signal. The frequency changes are then converted into usable signals. The major advantage of the Luft Detector technique is that the selectivity is increased by using the absorbance characteristics of the gas itself.

For flue gas measurements the Luft Detector technique was selective enough to provide measurements of CO2 and CO at relatively high concentrations but suffered several failings. First, the dual beam approach was very susceptible to fluctuations in the infrared source strength, dirt accumulations on the optics and mechanical alignment. Furthermore the mechanics of the diaphragm detector made the instruments quite sensitive to shock or even mild vibration. Few Luft Detector instruments were successful in the harsh plant environment.

B. Microflow Detector

In the mid 1970's several suppliers developed single beam and gas filled detectors that used techniques similar to the Luft detector, and were able to overcome some of their short comings. Most notably among these were the use of micro flow detectors which used a single beam technique and allowed flow to exist between the sample and reference chambers...measuring the flow with a solid state device was superior to measuring the movement of a diaphragm.

Several variations of this technique have been developed and the use of coexisting gases as a mask or interference correction in compensation detectors have been tried. Some improvement has been noted in rejection of CO2 interference by this method but it is not possible to capture water vapor in a compensation detector, thus water vapor interference remains a problem for these instruments. Figure 3 is a diagram of a popular micro flow detector technique.

C. Gas Filter Correlation

Gas Filter Correlation is a well known technique that first saw practical application for CEMS in the late 70's. Gas Filter Correlation approached the problem of selectivity from an entirely new direction...instead of trying to pick out specific wavelengths it would eliminate them. In the technique an optical bandpass filter is used to select an infrared band and then a cell filled with the pure gas of interest is placed in the beam--effectively blocking the energy contained in the spectral lines that the particular gas absorbs at. Alternately with the gas filled cell, a clear aperture with no absorption is placed in the beam. The result from the IR detector is the presence of two electrical pulses that represent energy levels, one missing the energy absorbed by the gas filled cell and the other containing all of the energy of the infrared source. If the IR beam passes through a sample cell that has none of the gas of interest, then the two pulses will be significantly different in amplitude. If the gas of interest is present in the sample cell then the ratio of the two pulses is reduced...in theory if the sample cell concentration is high enough then the two pulses will be the same amplitude with a ratio of 1. The Gas Filter Correlation technique is applicable to any gas that presents adjacent harmonic spectral absorption lines. Figures 4 and 5 describe the Gas Filter Correlation Technique.

D. Single Beam Dual Wavelength

Recent advances in optical filter technology have made it possible for purely optical techniques to provide selectivity similar to Luft Detector instruments. In the Single Beam Dual Wavelength technique ultra narrow band optical filters are used to select infrared wavelengths. One wavelength is at a spectral line that the gas of interest absorbs (measuring) at, and the other is one at which it does not (reference). Both wavelengths are of course selected to minimize the effects of other gases. Under a zero condition in the sample cell the two cells are alternately placed in the beam and the resultant electrical pulses are set as equal. If the gas of interest is present in the sample cell the measuring pulse is reduced in relation to the reference pulse and the ratio of the two is used to output a signal proportional to concentration in the sample cell. Figure 6 describes the Single Beam Dual Wavelength technique.

IV. SENSITIVITY

The ability to detect gases is dependent on the amount of infrared absorption which in turn is a function of the concentration of the gas of interest and the physical length that the infrared beam travels through the sample gas. For many low PPM measurements in the infrared this requires sample cell lengths as long as 30 feet. It clearly would not be practical for analyzers to be of such dimensions. This problem has been addressed by the development of folded path sample cells that, through the use of mirrored surfaces, reflect the beam back and forth through a modestly sized cell until long path lengths are achieved. Figure 7 explains the folded path cell technique.

V. CURRENT SITUATION

By the mid 1980's several infrared analyzers were available that could successfully meet EPA requirements for SO2 and NOx. Their use however was limited because no practical method was available for interference compensation in real-time. Because of their simplicity and reliability compared to other techniques these infrared analyzers never-the-less have enjoyed some popularity.

In this same time frame a German subsidiary of Perkin Elmer, Bodenseewerk, had developed an Infrared Analyzer that was able to combine a folded path sample cell with either Gas Filter Correlation or Single Beam Dual Wavelength techniques (The HCL version has gained wide acceptance in North America). In Germany the official Government Testing Agency, the TUV, must test all emission monitoring systems for interference rejection and relative accuracy before they can be installed. We therefore have some independent data to evaluate the current state of the art in infrared measurements of stack gases. Figure 11 is the reference method results of the TUV test on the Bodenseewerk gas filter correlation measurement of NO on a coal fired boiler. Figure 12 is a similar set of tests on the single beam dual wavelength SO2 version of the same instrument.

Figure 8 shows the interference effect of H2O on gas filter correlation measurements of CO and Figure 9 shows the interference effect of H2O on the dual wavelength measurement of SO2--both are without any compensation. It was known that if the H2O and CO2 contents could be measured then their interfering effects could be quantified and used to correct the measured gas signals. In addition since the interferent effect was strictly the result of optical absorbance, the ratios are vary stable. It was clear that real-time corrections for interferences were possible but the economic and practical constraints of adding instruments to an already complex and expensive system precluded field application.

VI. REAL-TIME INTERFERENCE CORRECTION

In 1987 Bodenseewerk developed a version of their very successful infrared analyzer that was capable of placing up to 16 gas filled or optical filters in the sample beam rather than just the two as before. The most important ramification of this development was that just one instrument could measure as many as 8 components and since stack gas analysis rarely required more than 6, two channels could be set aside for CO2 and H2O. Using a microprocessor control unit, then, would allow real-time correction for their interference effects.

All that remained for development was a method to control the filters and correct the signals for the interference effects. By mid 1988 this multi component infrared analyzer was fitted with a dual microprocessor Perkin Elmer Programmable Logic Controller and real time processing of emission monitoring data was possible. The instrument, called the Mekos 100, is programmed to select either gas filled cells or optical filters for insertion into the sample beam. The techniques which can be used simultaneously are Gas Filter Correlation and Single Beam Dual Wavelength. The software will decide not only which gas is to be measured but also which technique to use. Figures 10 describes the Mekos 100 configuration.

VII. SIGNAL PROCESSING

For stack gas analysis of SO2, HCL, NH3, NOx, or CO the primary need for signal processing is due to the interference effects of H2O and CO2 while a lesser interaction occurs between HCL and SO2. With the measurement of interfering effects it must be taken into account that the influence can be manifested in two ways.

An additive interference occurs with a spectral overlap. This is called additive since the interference causes an off set to the baseline and can always be corrected for by simple subtraction by the known interference ratio. Figures 8 and 9 are indicative of additive interference effects of water vapor.

Frequently an interfering component just influences the absorption coefficient of the component to be measured. For example, with increasing concentrations of water vapor the sensitivity for HCL increases. This kind of interference is called multiplicative since it will not affect the baseline, or zero, but only the sensitivity of the component to be measured. The amount of interference from multiplicative interferences are small compared to additive but consideration for them adds greatly to the precision of low PPM measurements.

In practice each measuring channel of the Mekos 100 is challenged with up to 10 levels of span gas and traditional IR linearization curves are generated in the computer. Then multiple levels of the interfering gases are also input and the effect on absorbance values are used by the computer to generate correction curves specific to each measured gas and interference. Each component measured can be corrected by up to three measurements, including outside signals if desired.

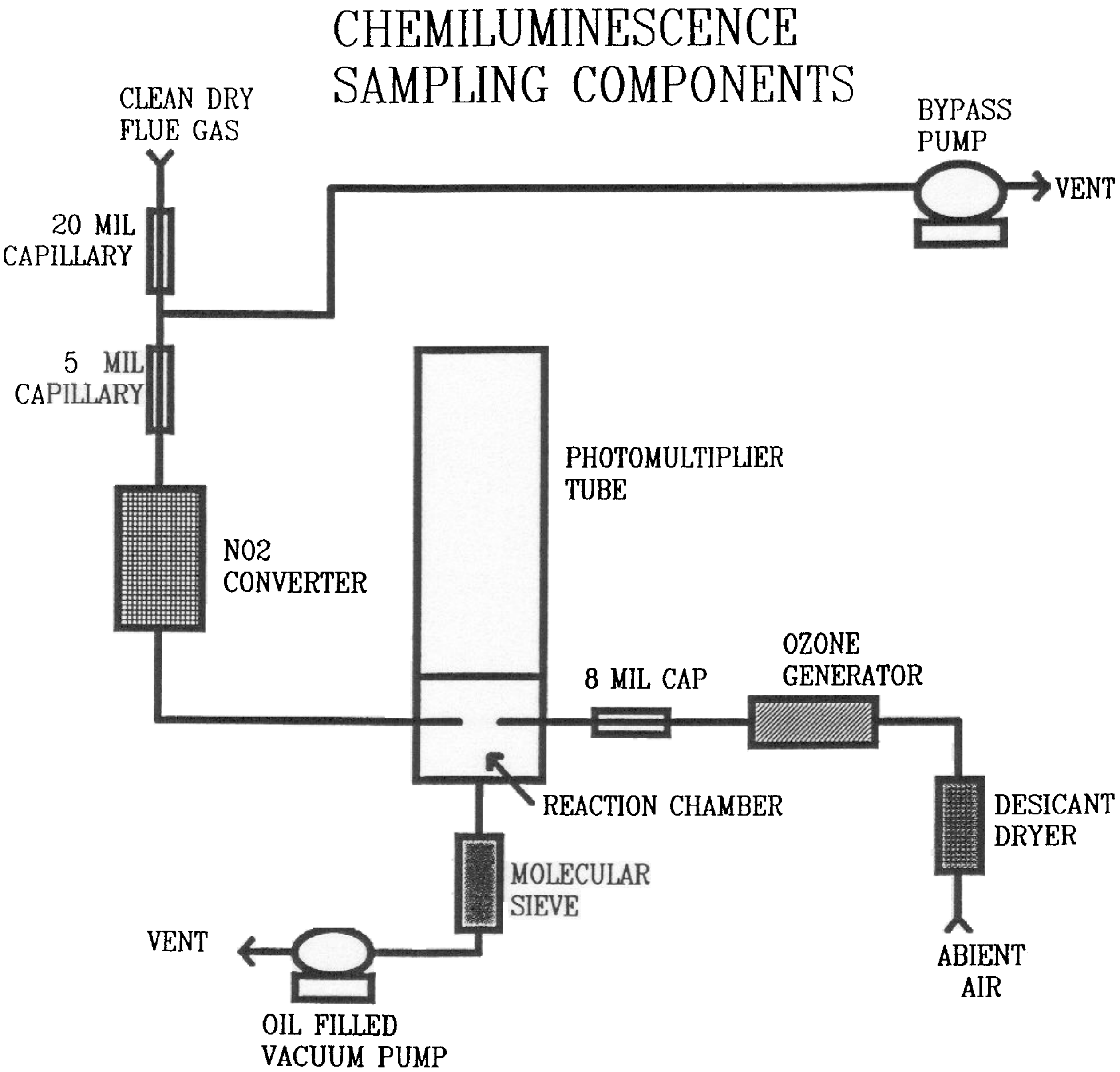
VIII. RESULTS

Approximately fifty Mekos 100 installations have been made in Europe starting in late 1988. Every installation has met the requirements for accuracy and reliability where installed. The official German Testing Agency, the TUV, has completed the laboratory portion of the approval tests on the Mekos 100 and all requirements have been met i.e. all interferences combined may not exceed 4%. The full formal test results will be available shortly. Presently over 10 Mekos 100 based systems are being installed in North America and certification test results should be available by early spring of 1990.

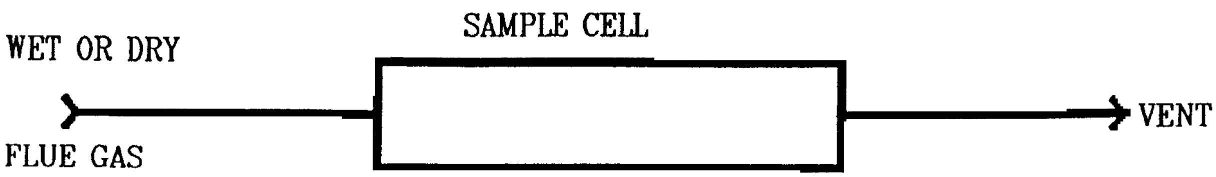
Figure 13 indicates the lowest ranges that are guaranteed to meet 40CFR60 requirements. The HW version of the system maintains the sample temperature above 200 degrees C and keeps the sample Hot and Wet(HW) through the analyzer sample cell. This is very important if reactive gases such as HCL or ammonia are to be measured. The cold dry version removes the water vapor prior to analysis and accordingly can control interferences within a narrow band and results in the ability to measure at very low ranges of analysis. It should be noted that even in the cold dry version water vapor concentration variations occur, even with small dryer temperature changes. Because of this it is also important to correct for water vapor variations leaving the dryer.

IX. SUMMARY

Infrared stack gas analysis techniques have improved significantly over the last two decades and can provide the accuracy and sensitivity needed to meet many stack monitoring requirements. Third generation multicomponent versions now can also measure interfering gases and, in real time, use microprocessors to correct for lingering interference effects. This approach now offers greatly simplified and less expensive analytical systems by using just one robust infrared analyzer to measure as many as eight gases, while providing uncommon selectivity and sensitivity.



CHEMILUMINESCENCE SAMPLING COMPONENTS



INFRARED ANALYZER SAMPLING COMPONENTS

figure 1

Comparison

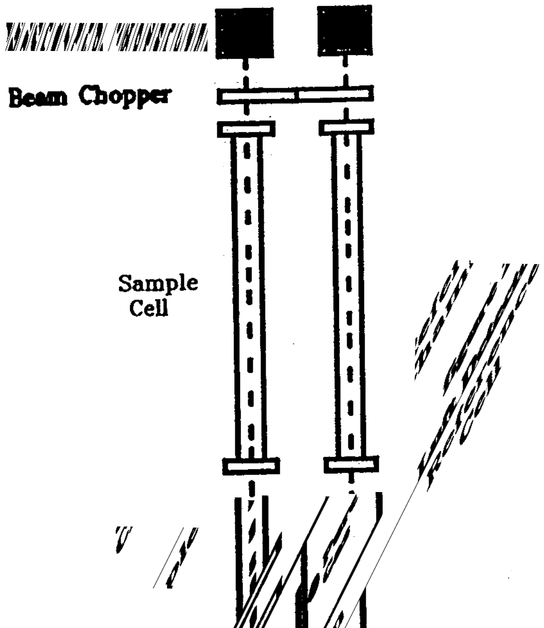


figure 2
Luft Detector

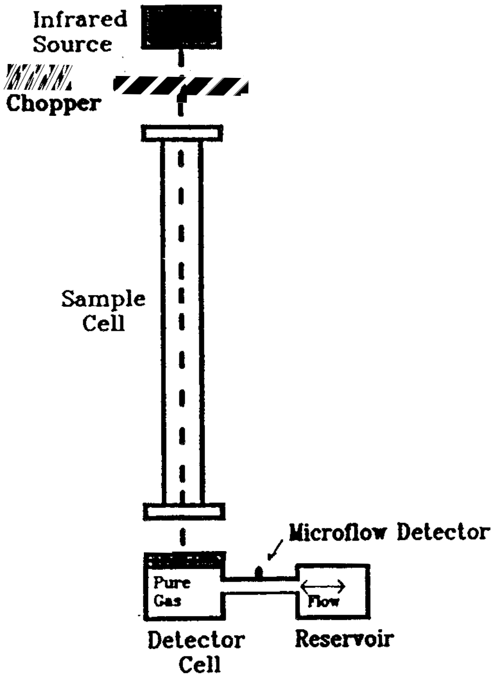


figure 3
Microflow Detector

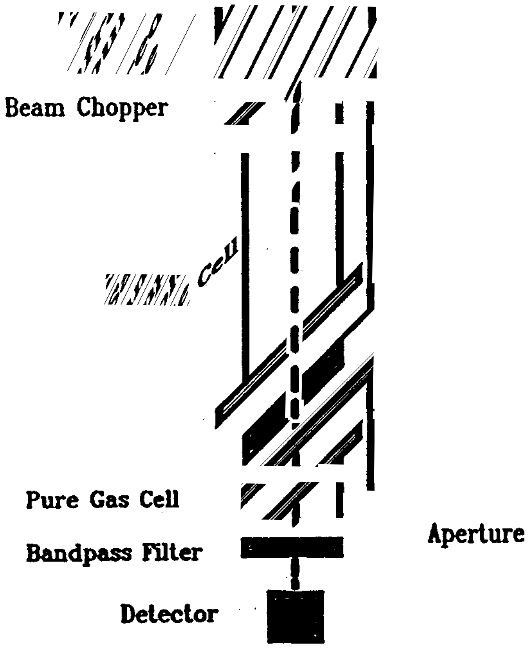


figure 4
Gas Filter Correlation

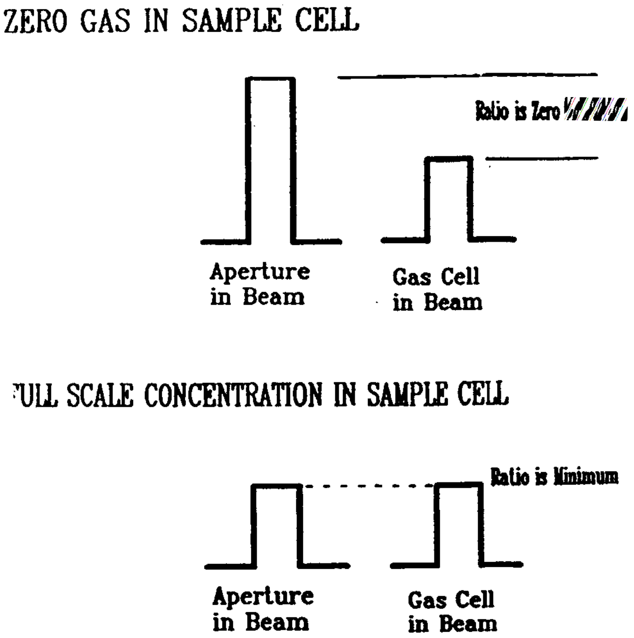


figure 5
GFC Waveforms

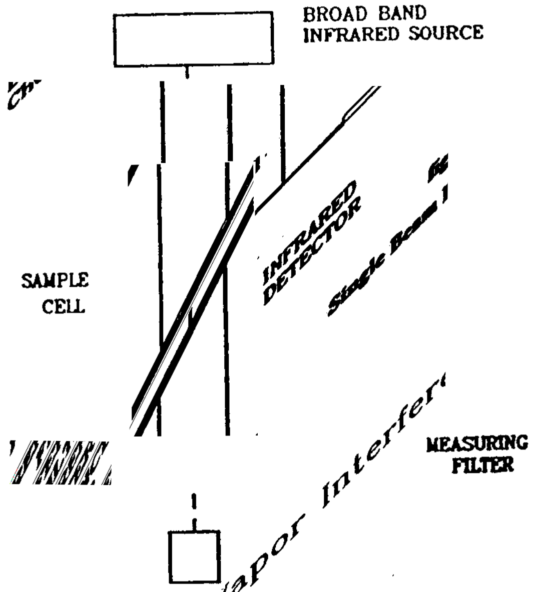


figure 6

Folded Path Sample Cell

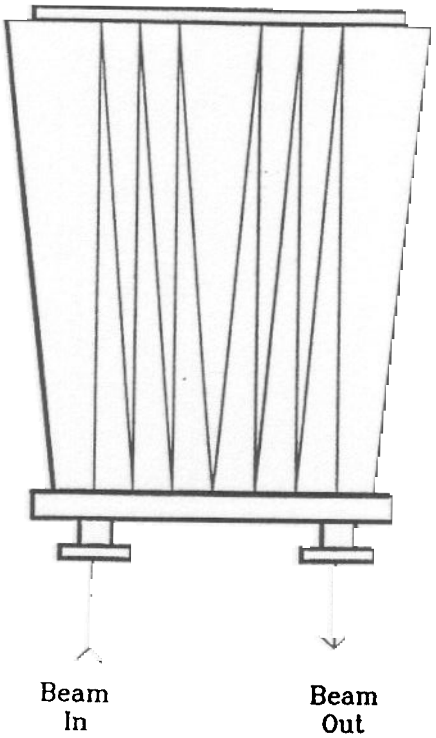


figure 7

Folded Path Sample Cell

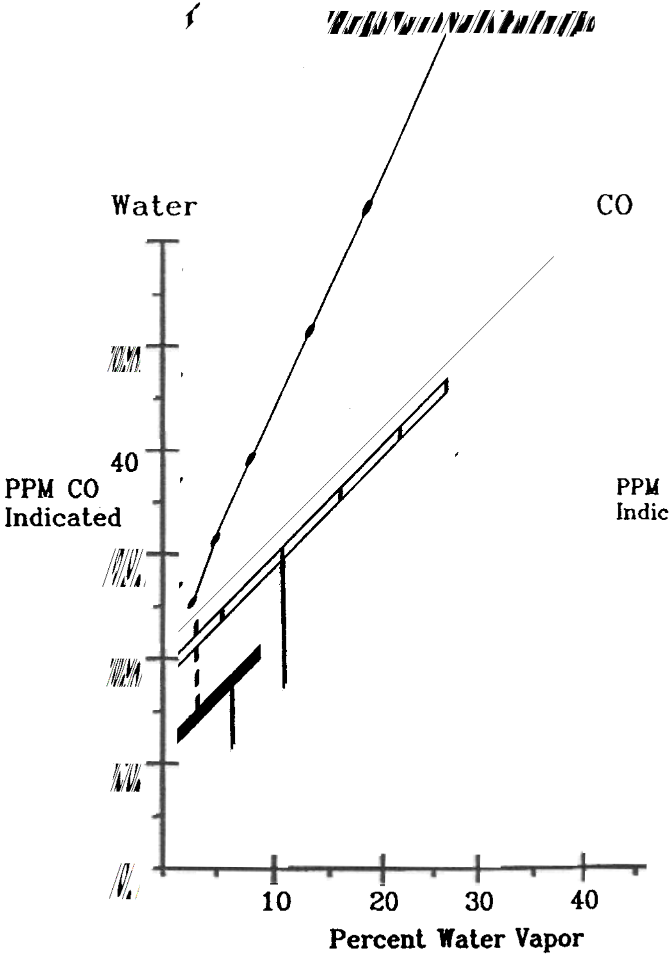


figure 8

Water Vapor Interference on CO

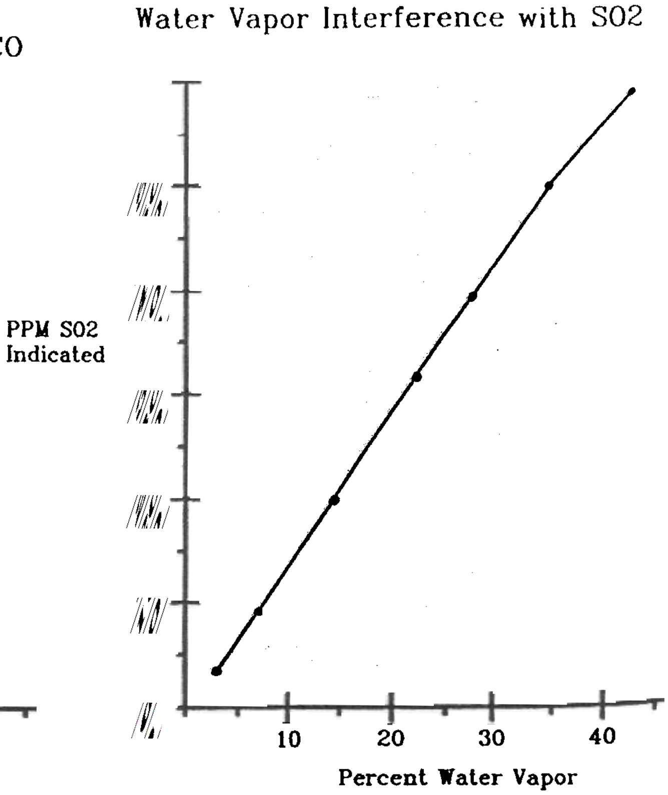


figure 9

Water Vapor Interference on S02

MEKOS 100
Multi-Gas Analyzer

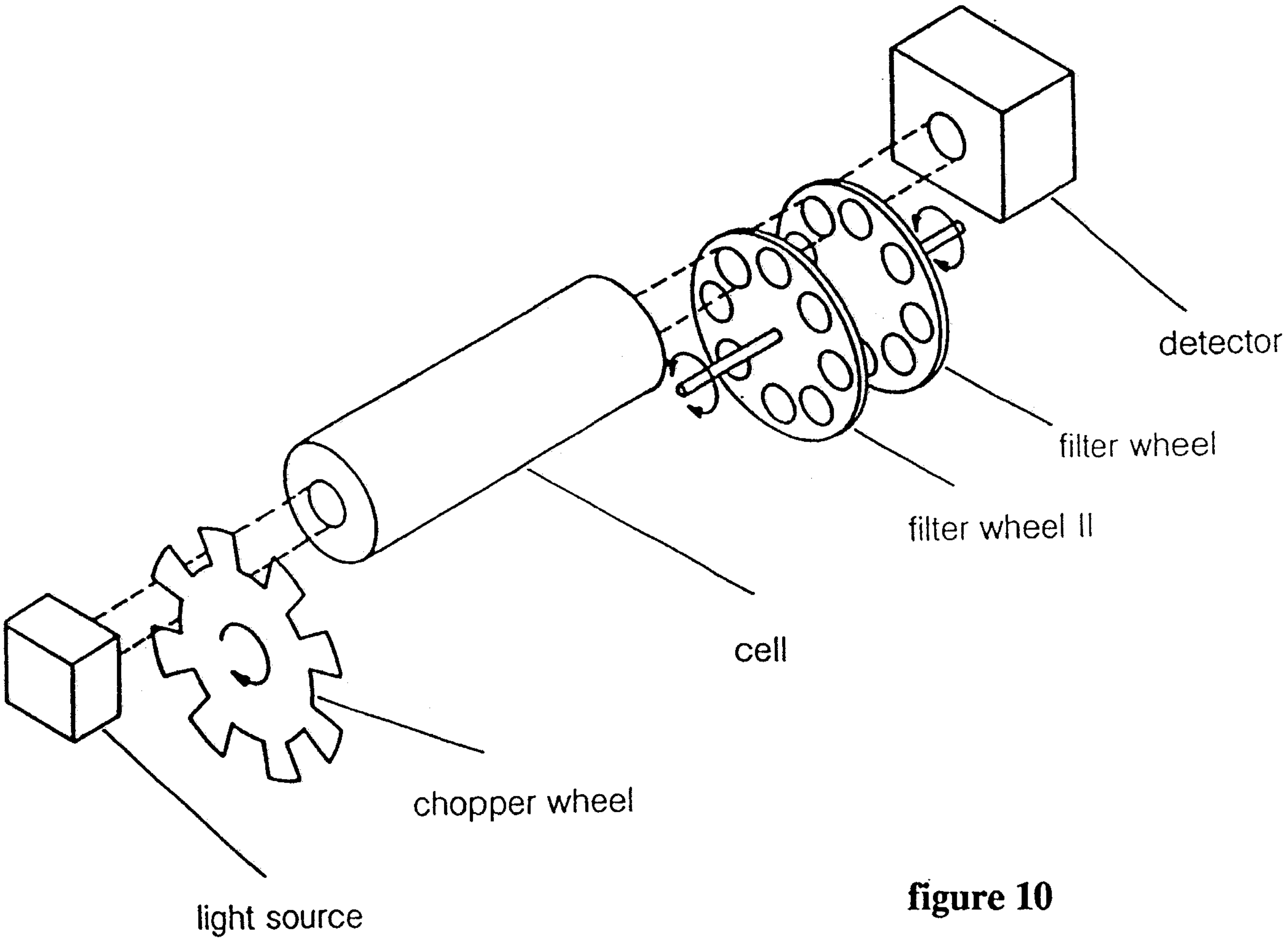


figure 10

Multi-component Analyzer

Meßwerte der Vergleichsanalysen Anlage B
(zu Tabelle 5.2.1)

	SPECTRAN 1 NO(mg/m³)	Analysen NO(mg/m³)
1	0	0
2	0	0
3	0	0
4	86	79
5	92	91
6	98	102
7	99	93
8	100	101
9	114	110
10	128	115
11	130	138
12	165	159
13	224	207
14	245	235
15	262	256
16	302	299
17	310	302
18	331	325
19	362	370
20	364	374
21	364	367
22	366	365
23	366	362
24	377	387
25	381	384

	SPECTRAN 2 NO(mg/m³)	Analyse NO(mg/m³)
1	0	0
2	0	0
3	0	0
4	75	79
5	88	91
6	89	93
7	96	101
8	97	102
9	103	110
10	118	115
11	141	138
12	156	159
13	205	207
14	232	235
15	257	256
16	288	299
17	297	302
18	320	325
19	347	374
20	348	365
21	348	370
22	350	367
23	362	362
24	365	387
25	368	384

figure 11

TUV Relative Accuracy Test for NO

Wet Chemical Reference Tests

Meßwerte der Vergleichsanalysen Anlage B
(zu Tabelle 5.2.1)

	SPECTRAN 1 SO_2 (mg/m³)	[redacted]
1	37	56
2	298	272
3	302	311
4	304	296
5	306	310
6	307	302
7	310	305
8	310	308
9	318	316
10	325	327
11	327	321
12	332	337
13	332	337
14	337	325
15	360	378
16	443	476
17	493	472
18	532	541
19	563	553
20	574	590
21	649	618
22	704	704
23	743	726
24	838	834

	SPECTRAN 2 SO_2 (mg/m³)	Analyse SO_2 (mg/m³)
1	40	56
2	276	272
3	297	310
4	297	311
5	297	308
6	298	302
7	299	296
8	301	305
9	313	316
10	320	327
11	321	321
12	325	337
13	327	337
14	330	325
15	351	378
16	460	476
17	483	472
18	522	541
19	564	553
20	576	590
21	636	618
22	692	704
23	744	726
24	852	834

figure 12

TUV Relative Accuracy Test for SO2

ALTECH HW
System Specifications

All components at 185 C or above.
Sample Cell Path @ 10 meters

GAS	LOW RANGE	METHOD
NH3:	0-20 PPM	GFC
HCL:	0-20 PPM	GFC
SO2:	0-30 PPM	SBDW
CO:	0-35 PPM	GFC
NO:	0-50 PPM	GFC
CO2:	0-20 %	SBDW
H2O:	0-40 %	SBDW

NON-LINEARITY:........Less Than 1 % Of Span
CROSS SENSITIVITY.....Less Than 3 % Of Span

ALTECH CD
System Specifications

Dried Sample at 2.5 C Dewpoint
Sample Cell Path @ 6 Meters

GAS	LOW RANGE	METHOD
SO2:	0-10 PPM	SBDW
CO:	0-35 PPM	GFC
NO:	0-50 PPM	GFC
NO2:	0-15 PPM	SBDW
CO2:	0-20 %	SBDW
H2O:	0-5 %	SBDW

NON-LINEARITY.........Less Than 1 % Of Span
CROSS SENSITIVITY.....Less Than 1 % Of Span

figure 13

Specifications