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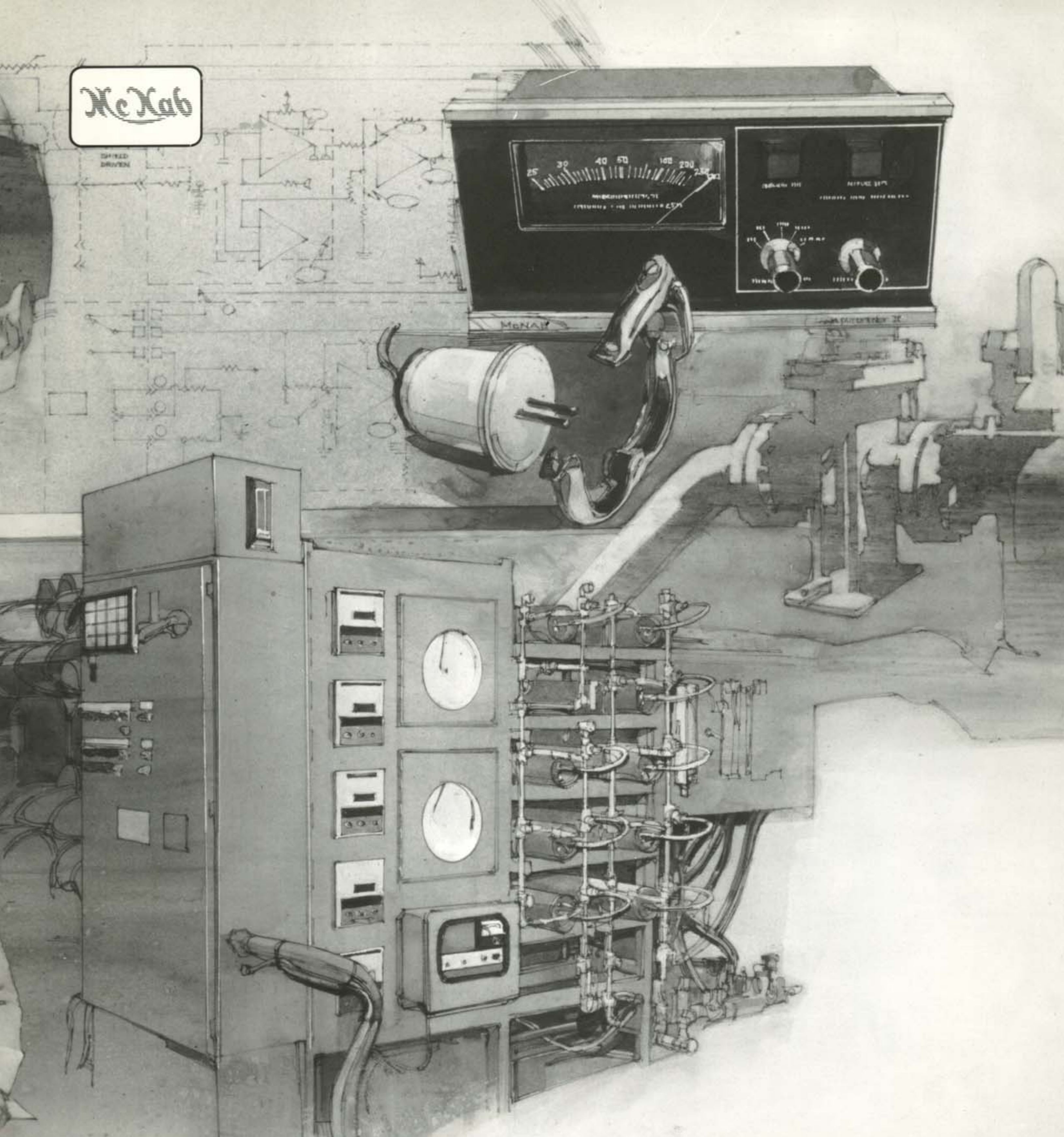

HANDBOOK

OPTICAL MEASUREMENT OF IN-PROCESS FLUIDS

OPTICAL MEASUREMENT
OF
IN-PROCESS FLUIDS

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PROCESS TURBIDITY MEASUREMENTS

In 1974, the National Oceanic and Atmospheric Administration recommended, after due deliberation, to call turbidity a "non-technical appearance descriptor." While turbidity certainly has become a common description, relied on in many industries, it still is accurately defined as an "appearance descriptor."

What this means is that turbidity is a human phenomenon. It is the "reduction" of transparency due to the effect of particles. Clarity or clearness is the lack of turbidity. Turbidity is, only in part, the effect of suspended particles on light passing through a liquid.

WHAT TURBIDITY IS NOT!

Turbidity is not just an optical measurement of percent solids. It is an "optical property" of the liquid. Turbidity is not color, but it is affected by intensity and hue of color, direction of illumination, background and path length. If you change the color of a liquid by dissolving a dye into the liquid, you will change the observed effect of the liquid on light passing through it, but you will not change the turbidity, were turbidity considered only particles, but its optical properties would certainly change.

Note, however, that light absorption or scatter signals will often follow the concentration levels of particles in the liquid. This relationship is often used to analyze concentrated levels from near zero to 60% concentration (by weight or volume).

Turbidity is also not empirical. You cannot run a liquid through filter paper, or evaporate it by some other means and measure the turbidities that remain (e.g. color aspect). Turbidity is not, therefore, absolute. If you want to change or maintain the turbidity properties of a liquid from day to day, then you must first agree upon how you'll measure, and use a similar measurement technique each time.

WHAT IS PROCESS TURBIDITY?

The use of the term process to modify turbidity is generally taken to mean that the visual measurement of a pipe carrying product is being made "full time" or continuously.. Process implies here that there is a product being made in either a continuous or batch method. Turbidity measurements are made on this product "on-line" or "in-line-across the pipe" as the product is made.

If you take a sample of the product from a pipe to measure the turbidity, it is no longer a "process" measurement. Process turbidity measurement, therefore, is not "laboratory," "table top," or "grab sample" measurement. We have noted significant variations between the actual process optical measurement and the subsequent laboratory results which are often attributed to the laboratory sampling and handling procedures.

Process turbidity measurements can be made on a bypass line "on-line". For example, if there is a 56-inch diameter main line associated with the product, a smaller line may be brought off the main line on a bypass and the turbidity measured there. While this is process turbidity measurement, the use of the bypass is not desirable practice because particle concentration and size distribution are altered by effects inside the process line and sample line. Further, temperature decreases caused by a bypass may have a profound effect on particle concentration levels.

Laboratory measurements are often used to check performance of a process turbidimeter. These correlation studies must be carefully evaluated for temperature, color, time, sample technique and procedural errors.

TURBIDITY OR PARTICLES MEASUREMENT

To some, turbidity is a hazy concept. For process or QC work the visual effect, turbidity, is to be replaced by photometer readings in parts per million (PPM) to gain precision. Usually for a process engineer to say something is not hazy or too hazy is not precise enough to establish, for example, proper particle weight to the light effect. This can establish an instrument calibration curve.

As will be seen, "turbidity " is inappropriate as it includes the effects of increasing background color, etc., reducing/masking the apparent "turbidity" in the situation of constant particles. Therefore, modern process operation control specifications calling for mere turbidity may include color interferences, and will produce a control signal proportional to the particle and background color… an unsatisfactory instrument. The use of "turbidity instrument" in specifications should be discouraged, or carefully reviewed for its applicability.

ABSORPTION TURBIDIMETERS (Figure M21417-2)

Photometers subdivide down into to two basic types: absorption (as the McNab Model HSA) and scattering (as the McNab Models HSB and RS). In an absorption system, a beam of light is interrupted by a sample of liquid. Light enters the liquid and the amount of light leaving the liquid is reduced due to scattering and absorption when the light enters the liquid container (e.g. the window glass of the meter), reflection from the glass window/liquid interface, absorption due to the color of the liquid, scattering and absorption of light due to suspended particles and then the same sequence of scattering and absorption at the liquid/window interface and window/air interfaces of the receiving light scanner. The losses due to all liquid scattering and all absorption of the particles constitutes turbidity. Other names for this are the "lost light", "straight through," or "transmission turbidimeter".

The absorption photometer has limitations distinguishing small light changes against the large amount of light that passes through a near clear liquid. Therefore, using the absorption principal at very low particle levels is poor practice. Medium to high concentration liquids are best measured using the absorption method. However, low particle concentrations are best measured using a scatter design.

SCATTER TURBIDIMETER (Figure M21417-3)

The scatter design also interrupts a beam of light with the liquid to be measured. Again, there is scattering and absorption in the liquid container window and in the liquid. With this design, however, the amount of light just scattered by the particles in the liquid is measured at a right angle to the beam. Where particle concentration increases, so does the light signal increase. In absorption, you find the opposite – decreased light with increased concentration. Unlike the absorption method, it has a large change in signal when it goes from no particles measured, (and therefore no scattered light), to having some particles measured and some scattered light. This characteristic makes the scattered light method more sensitive as well as repeatable for low concentration measurements.

As particle concentration levels increase, however, more scattered light is lost in the liquid due to the secondary diffusion and absorption off of the many particles. Less light leaves the liquid sample than should otherwise occur, giving too low a reading of scattered light. In these ranges of medium to high concentration, the absorption method may be a better choice. At ultra-high concentration, the scattered light method is again needed as light cannot penetrate the high concentration levels.

The scatter method may also be called a haze meter or Tyndall nephelometer. To be correct, an absorption meter may be a true turbidity style meter (reading everything), while a properly designed scatter meter is considered a haze meter. The measurement distinction between haze meters and turbidity meters and photometers has, however, been confused over time, and all of these measurements are now sometimes incorrectly called turbidity measurements.

UNITS OF MEASURE

The measure of turbidity is a relatively young science. Leonardo da Vinci speculated around the year 1500 that the blue color of the sky was due to light scattering of water particles in air. It wasn't until the late 1800's that Tyndall and Rayleigh started the scientific study of light scattering.

As the science has evolved, so has the definition of units. Early turbidimeters did not consider light scattering measurement completely. They simply used the absorption method. Relative turbidity, percent transmittance and sometimes JTU (Jackson "Candle" Turbidity Units). Later work using scatter design promoted units such as PPM (Parts Per Million of a standard substance), TE/F (of Formazin) European units, and Kieselguhr (SiO_2) units.

Realization of the sensitivity and particle selectivity aspects of scattering meters brought the name Nephelometric Turbidity Units (NTU) to describe measurements resulting from a light scattering meter. Certain scattered light meters are, therefore, more correctly referred to as "nephelometric turbidimeters," where the detector picks up only 90 percent of scattered light.

Where the measuring light beam picks up at an optical angle more than 90 degrees from the projected beam target, it is sometimes known as backscatter, and where the angle is less than 90 degrees, it is known as forward scatter measurement. For optical, scatter instruments, some degree of "angle" standardization has been achieved in the world. It has in large part been limited to laboratory measurements. Usually the measurement scatter angle is at 90 degrees per the American Society Testing Materials (ASTM).

The American Society of Brewing Chemists has settled upon a particle standard, using Formazin solutions. These units have become a standard in the U.S. brewing industry, commonly called ASBC units. The European Brewing Congress has established a similar standard as well. It, unfortunately, is not equal to ASBC. Roughly speaking, 1 EBC unit can approximate 69 ASBC units.

Particle size, range and sensitivity to particle size are affected by scatter measurement angle. We have found that the 90 degree scatter system has in about a half decade increased range in small particle sensitivity and, with decreased size, "peaking" of response. Both affect or make the 90 degree angle much more desirable in particle measurement. Earlier 90 degree scatter designs not using "at pipe" preamplifiers have inadequate signal levels and were not well thought of. This noise sensitivity confused early studies of the 90 degree technique.

Raw water turbidity measurements, on the other hand, are given attention by the American Water

Works Association (AWWA) and the Environmental Protection Agency (EPA). The units of measurement in this case are the NTU (Nephelometric Turbidity Units) that we discussed above. Color interference in not typically a consideration in this application

The potential for confusion exists, then, since an industrial plant may require 0.5 NTU (a typical EPA standard) water from the local water authority, and the process may then produce product on the order of 35 - 60 ASBC or 0.5 - 0.8 EBC.

RATIO COMPENSATION METHODS (Figure M21417-4)

The transmission/absorption method in Figure M21417-2 and the light scattering method in Figure M21417-3 will indicate a change in signal when light received at detector "D" decreases for any reason. This can be due to a parameter increase of particles, presence of color, build-up of material on the windows or even reduced output from the light bulb. These matters act as an interference and, if not corrected for, would distort the correct particle readings and would be perceived as particles decreased, when in actuality, the particle PPM level remained the same. To eliminate these "interferences", we may use a ratio method of compensation. This is suitable for forward and 90 degree scatter methods. In ratio signal processing, the design goal is to suppress interference effects of the background... that is, changes in other parameters than the particles. To do this, we measure the background light, background and scatter light, and then electronically divide one by the other.

On the other hand, in a transmission absorption photometer system there is no ratio signal D available to correct for background error. Hence, its signal is subject interferences, but where the error is color induced, a matching colored filter may be put in to intercept color hue bias, possibly rendering the photometer free from color effects. These are techniques to limit the interferences.

SYMETRICAL RATIO SCATTER METHOD

Figure M21417-5 shows a illustration of how such a currently designed 90 degree scatter ratio is laid out. Detector N (Normal) measures the scattered light transmitted, minus losses due to build-up on windows, bulb changes, color, etc. On the axis of direct light (as in a transmitter type meter), the Detector D (Direct) measures transmitted light, again minus losses due to build up on its windows, bulb changes and color. The ratio, N scatter signal divided by D (reference) is, therefore, changed only by the reflected scattered light.

For example, in a properly constructed equal path 90 degree optical chamber, a non particle color signal is seen as "color loss" in the N (Numerator) and "color loss" in the D (denominator) where the path is symmetrical, then the electronics division will automatically ratio "color loss" out of the displayed meter reading. This design is of major importance to the user in that it (1) stabilizes or automatically corrects for adverse instruments optical zero drifts and (2) the signal is proportional to actual particles rather than turbidity or color.

It is worth noting, the theory is that color correction works in the 90 degree design because of same optical (balanced) path for scatter and reference. This is not true in other configurations. For example, in the "forward scatter" design (Figure M21417-6) the forward scatter signal path length is somewhat longer than the reference/transmitted path, preventing complete automatic ratio correction of color and, hence, an error effect on particle concentration readings.

FORWARD SCATTER RATIO DESIGN (Figure M21417-6)

A forward scatter design is illustrated in Figure M21417-6. Electrically, it is similar to the ratio scatter method in that the forward scatter signal is divided by the reference detector (D) signal, resulting in a partly compensated measurement.

In this ratio construction, instead of either a three or four individual head system, there are only two. Both the scatter and transmitted light are detected in a combination head. In actual practice, the glass windows deteriorate proportional to velocity and concentration. Where the window is sheltered from flow there will be less deterioration or more potential foreign substance plating. This unevenness disturbs the optical balance between forward scatter (window rim) and transmitted light (window center), resulting in a less stable optical system as compared to the balanced scatter system found in the 90 degree design.

USE IN THE REAL WORLD

While the above discussion is simplified, in the real factory environment many other things must be considered. The system must be rugged in construction so it is liquid tight at factory pressures and temperatures. Yet it must also be easy to service and clean. Materials of construction must be compatible with, and impervious to, the fluids in the pipe.

Figure M21417-5 shows a balanced ratio turbidimeter with the additional feature of a test lamp, Lamp #2. This makes nephelometric measurements with compensation for coating, color changes, etc. In addition, Lamp #2 can be lighted by a panel switch. This action causes an apparent increase in scattered light. This will upset the ratio, driving up the resulting signal, and cause an increase in apparent particles. Use of the test lamp confirms that Detector N is intact and working, and that the wiring is complete between sensor and control electronics. By changing the alarm status, it also confirms that any alarm wiring is intact and functioning. In the real world, it is helpful to be able to periodically check that the wiring hasn't been removed overnight by a misguided fork lift truck. This functional test provides this check.

The balanced ratio compensation and the function test are features that help the theoretical unit withstand the rugged, harsh factory environment and yet read particles (PPM) free of interferences.

Periodically, fluid samples will be taken and checked for particle concentration on a laboratory instrument. This is another form of "real world" function test (Figure M21417-11). Not that the optical angles and design between the laboratory instrument and the in-line instrument should be the same. Preferably, instruments should be from the same manufacturer.

TWO-ANGLE SCATTER DESIGN (Figure M21417-8)

A later design combines one set of optics – 90 degree and forward scatter concepts – and they operate as described before. However, because of the limited range of the forward scatter particle size sensitivity, the instrument operates as a special case of a particle size analyzer. The 90 degree signal will provide a signal that, when subtracted from the forward scatter signal, will emphasize 0.2 to 1 micron size particles.

The exterior of such a system, the McNab Model DSB, appears like the balanced ratio scatter system that has four heads. Two individual electronic processors are included for simultaneous readings of the two scatter ratio corrected signals.

BACKSCATTER DESIGN (Figure M21417-7)

The backscatter design is unique as compared to the previously mentioned optical configurations. This is so because it has only one head. In this case the transmitted light is sent into the tank and the light is reflected back to the detector (N) and is proportional to the particle concentrations in the tank. By dividing N by D (D being the reference signal), bulb variation effects can be automatically accounted for. This instrument has optical characteristics similar to that of an absorption system. Hence, color compensation is arrived at through filters. This instrument is useful in large diameter pipes, tanks or reactors. This is McNab's Model HSD.

APPLICATIONS OF PARTICLE CONCENTRATION ANALYZERS AS MONITORS

The process scatter meter described so far is a "turbidity monitor." It monitors the condition of the liquid. It may report the particles to a remote device for logging data (data logger, computer, etc.). It may also have the ability to close a contact and ring a bell or light a warning lamp when too high (or low) a particle concentration is measured. This is usually called an "alarm point," and it is usually sete in the field by the operator.

Figure M21417-9 shows analyzers in a monitor application. The solids removal system can be a filter; for example, a diatomaceous earth filter or centrifuge. The meters monitor the particle concentration of the liquid both before the filter and after. These two measurements can be compared. This will measure the effectiveness of the filter. The alarm on the input (left) side can be used to warn the operator when the filter is in danger of being temporarily overwhelmed by too much incoming solids. The alarm on the output (right) side can be used as a quality control device.

It can warn for filter failure when an unfiltered product is being produced. Also, it can warn when filter media or other contaminants are in the product flow. In addition to warning, the meters will monitor (and record, if desired) what the actual particle level is of the finished product. Note the above is a particle concentration and it would be an error to use a "turbidity meter".

APPLICATION OF PARTICLE CONCENTRATION ANALYZER IN CONTROL FUNCTION

Figure M21417-10 shows meters as active control devices in a control loop. This was an early (about 1977) example of a control system. In this example, the solids removal system is a filter that requires the addition of a filter aid into the product flow stream for proper operation of the filter. The amount of filter aid required is proportional to the amount of solids to be removed. The input meter, therefore, measures the particle concentration of the incoming product and uses this information to control the addition of filter aid.

Since body feed is proportional to the input solids content, the controller turns on a body feed pump when it senses particles due to solids in the flow stream. If the solids content increases still more, the controller senses this and turns on a second pump to increase the amount of filter aid in the flow stream. Variable speed pumps could also be used, and a proportional 4-20 mA signal from the turbidity controller would accomplish variable addition of filter aid.

The need for the control action could be removed by just running the pumps to add filter aid all the time. Some sort of control is, however, needed because (1) the filter will have a limit on how much filter aid it can accept, (2) filter aid is an expense that must be more closely controlled than full-time pump operation allows, (3) some filter aid has an excessive disposal cost due to purported health hazards. It is these savings in filter aid cost, and reduction in problems during operation of the filter, that justifies the expense of the control loop installation.

The design of a control system involves more than just installation of an optical analyzer. All the elements in the control system must be considered. In Figure M21417-10, for example, dimensions are marked on the illustration. This should be considered by the engineer so he realizes that there will be a delay after injection of filter aid while it travels to the filter.

Figure M21417-12 is an example of results from an actual control system, in this case pH. In this example the system is in oscillation (See A) due to too much pH reagent addition. The pump adds too much material before the sensor realizes the increase. Electronic signal conditioning is used here to compensate for the oscillation (See B). Despite dramatic changes in the chemical composition (Area C) the system in each case responds automatically, and restores the chemical to the desired conditions (Area D). In a likewise manner, the diatomaceous earth (DE) can be added to the filter for matching exactly the optimum ratio of mixing.

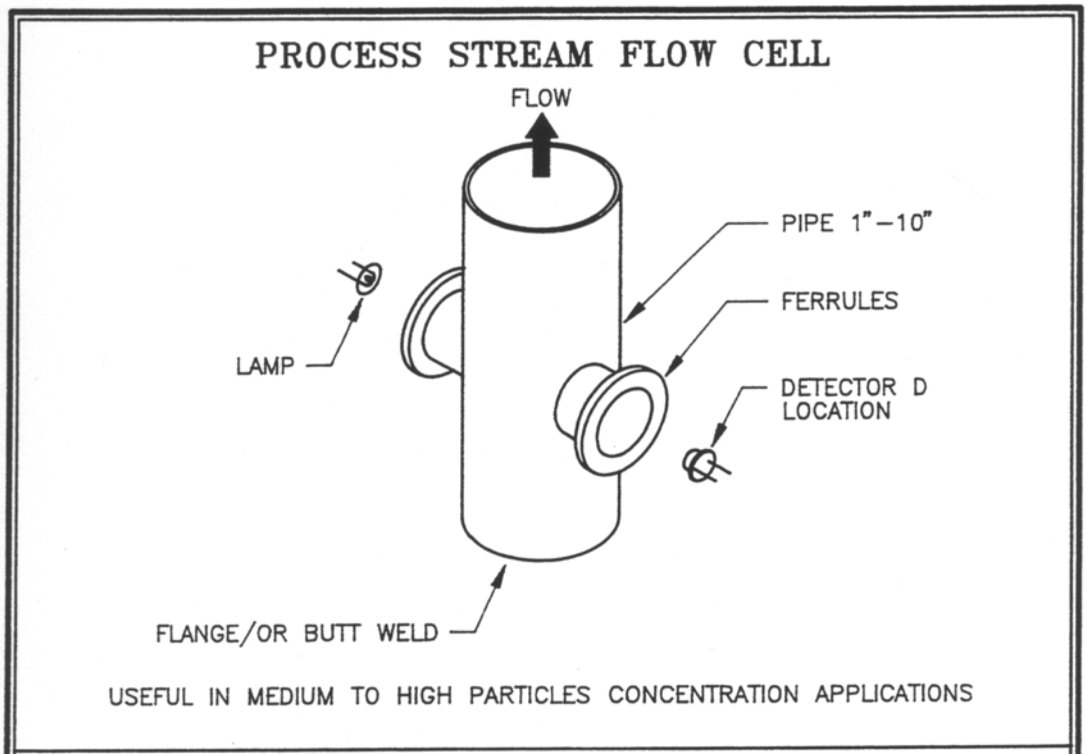
SUMMARY

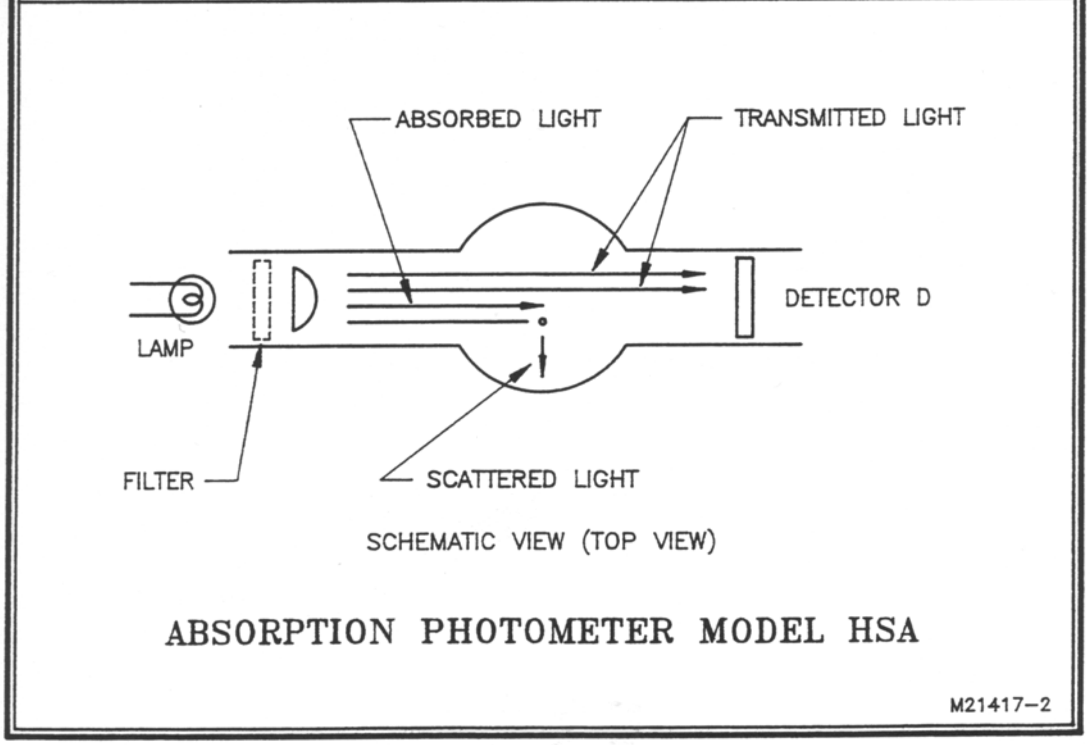
We have seen that turbidimeters measure an optical property of liquids caused by particles and color in the liquids. A balanced ratio analyzer has techniques to suppress optical effects not caused by particles in the liquid. Hence, it is a more practical tool in control and manufacturing.

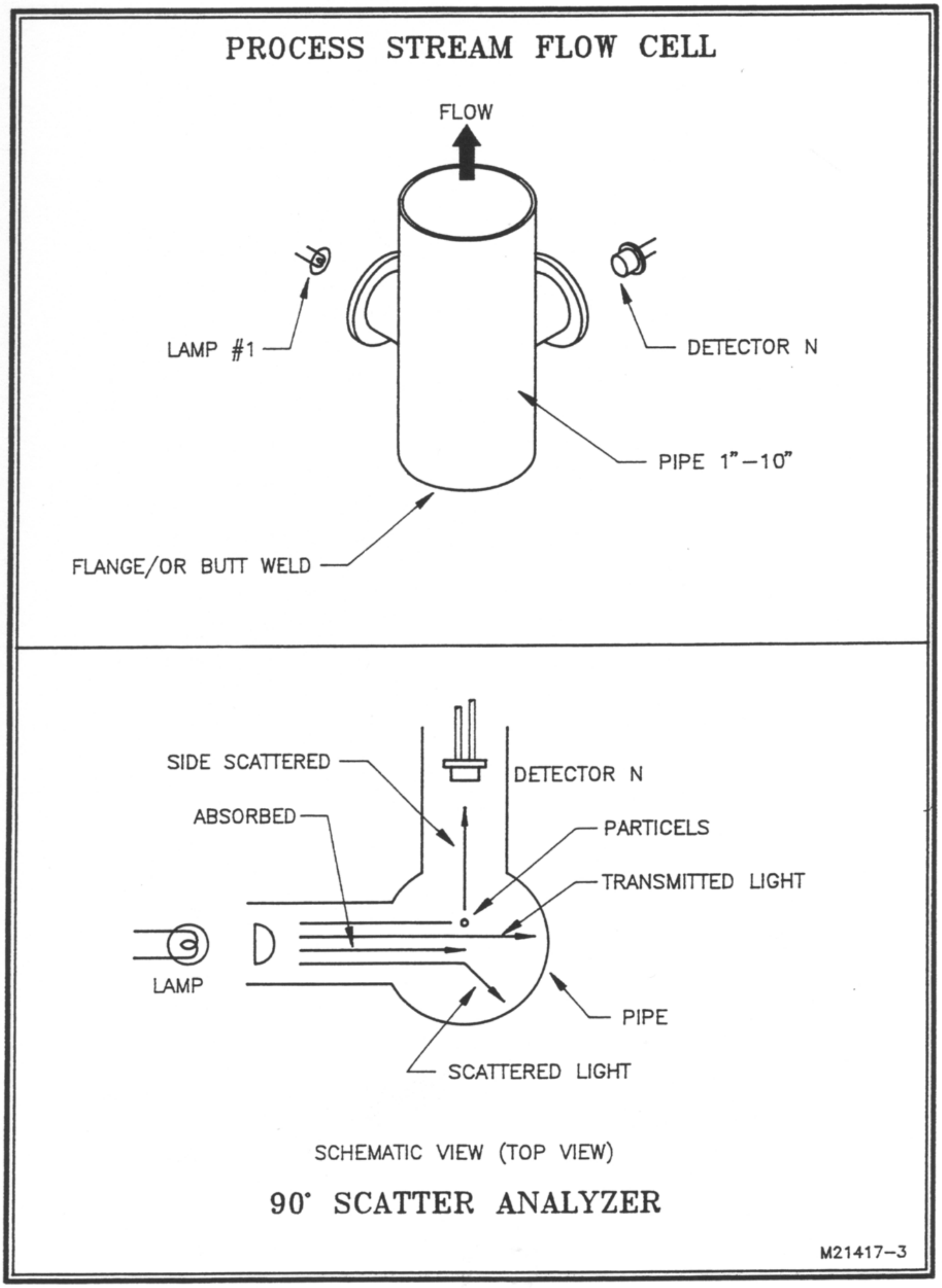
Particle measurements can be used in a manufacturing environment to continuously monitor the performance of a specific filter or the quality of a finished product. Such analyzers also become active control devices, changing a process continuously as conditions require.

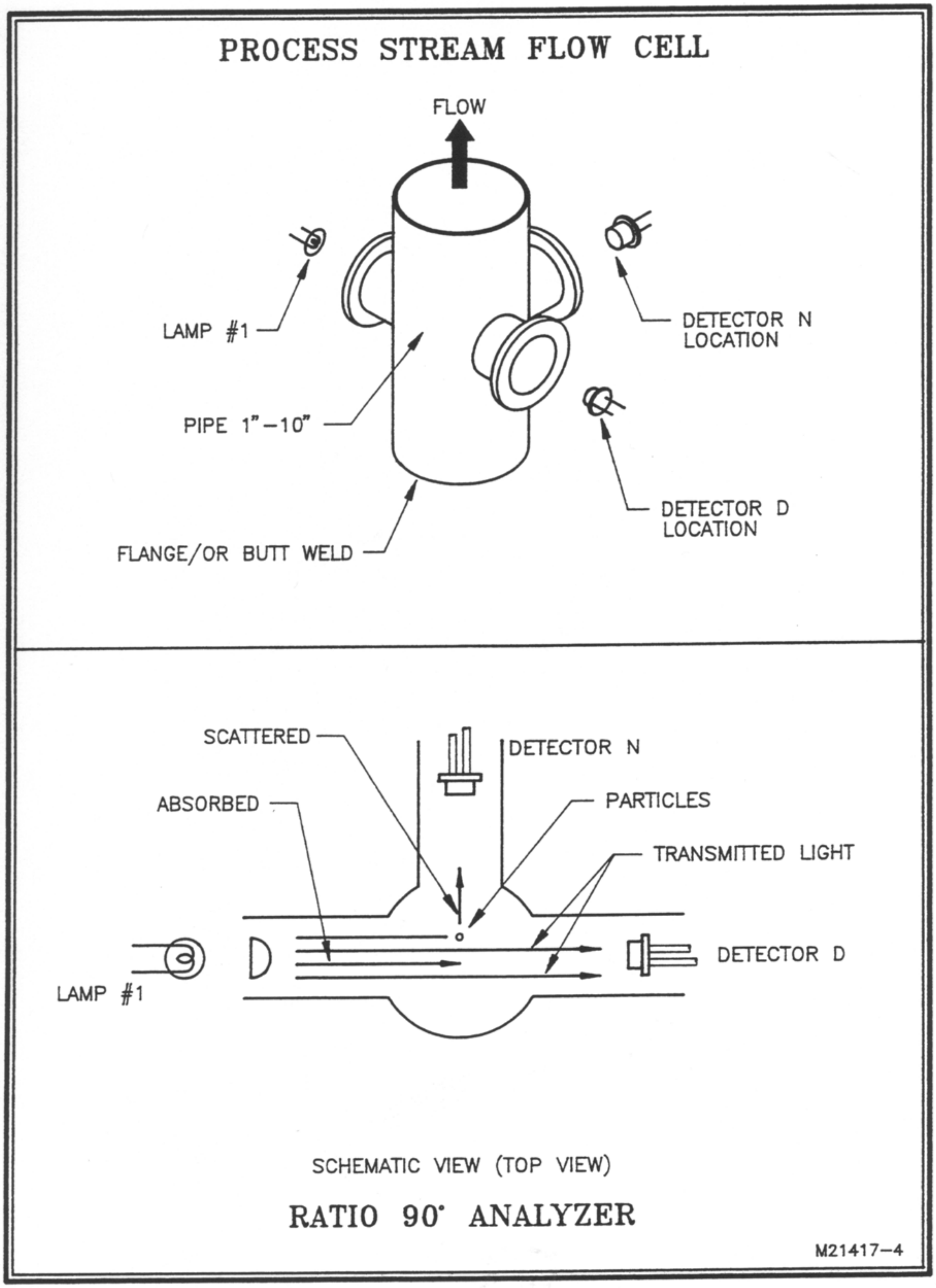
The turbidimeter has evolved from non-selective measurement to a selective measurement of particles as well as a rugged, reliable device, designed for continuous use in the factory environment.

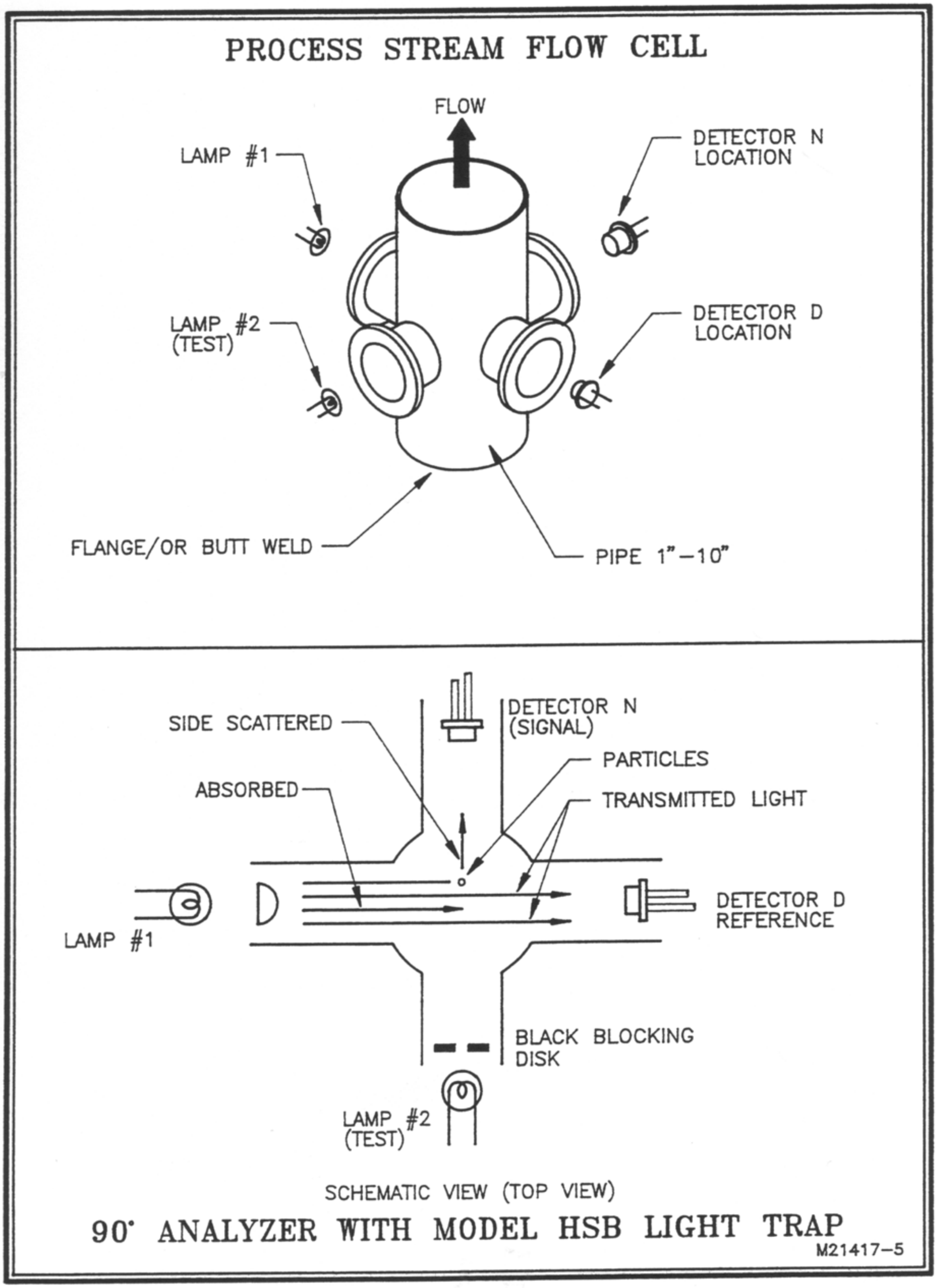
THIS PAPER WAS PRESENTED TO THE MASTER BREWERS ASSOCIATION OF THE AMERICAS.

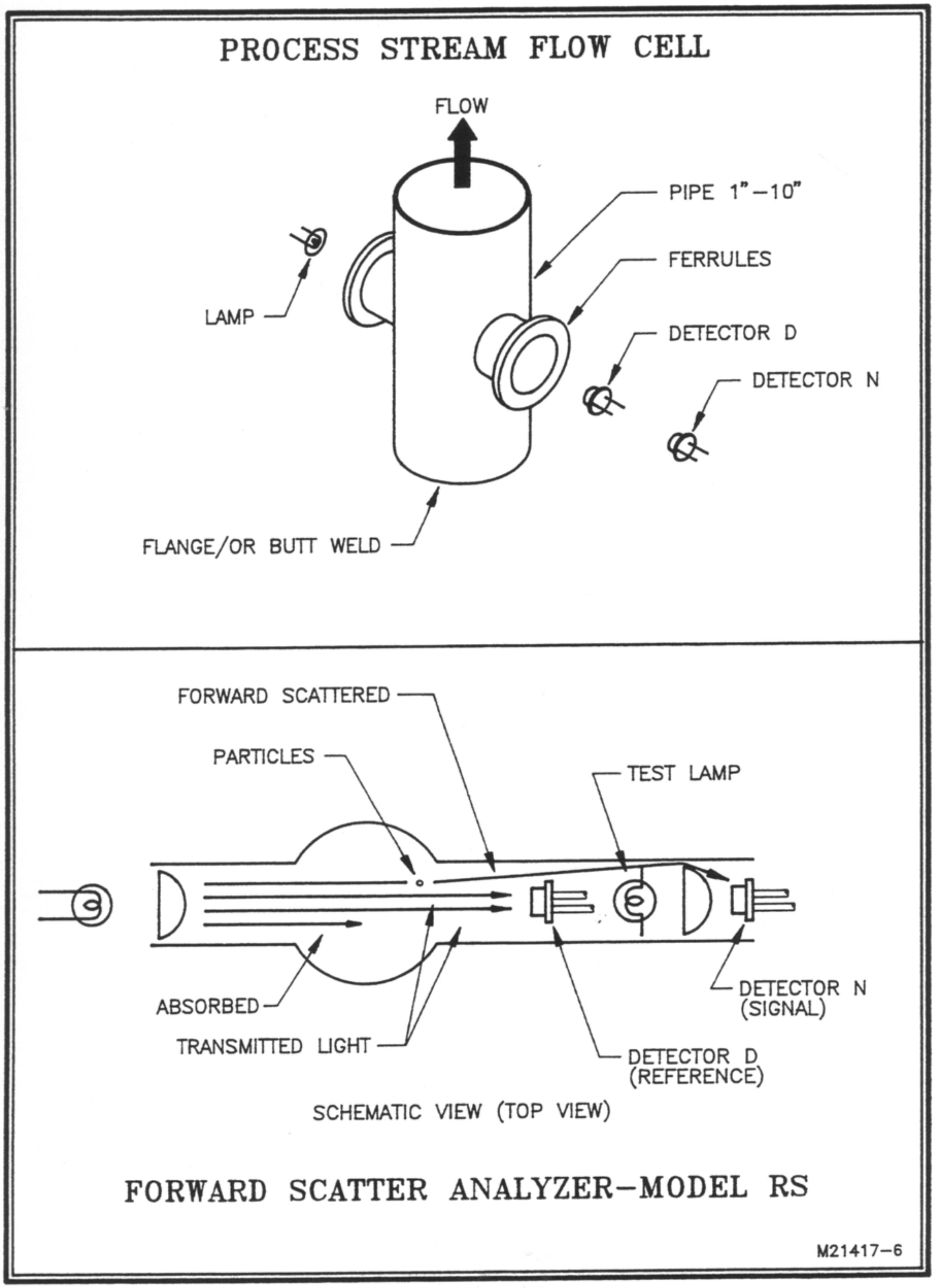

PROCESS STREAM FLOW CELL
FLOW
PIPE 1"–10"
FERRULES
LAMP
DETECTOR D
LOCATION
FLANGE/OR BUTT WELD
USEFUL IN MEDIUM TO HIGH PARTICLES CONCENTRATION APPLICATIONS


ABSORBED LIGHT
TRANSMITTED LIGHT
DETECTOR D
LAMP
FILTER
SCATTERED LIGHT
SCHEMATIC VIEW (TOP VIEW)
ABSORPTION PHOTOMETER MODEL HSA
M21417–2


PROCESS STREAM FLOW CELL
FLOW
LAMP #1
DETECTOR N
PIPE 1"–10"
FLANGE/OR BUTT WELD
SIDE SCATTERED
ABSORBED
DETECTOR N
PARTICELS
TRANSMITTED LIGHT
LAMP
PIPE
SCATTERED LIGHT
SCHEMATIC VIEW (TOP VIEW)
90° SCATTER ANALYZER
M21417–3


PROCESS STREAM FLOW CELL
FLOW
LAMP #1
DETECTOR N LOCATION
PIPE 1"–10"
DETECTOR D LOCATION
FLANGE/OR BUTT WELD
SCATTERED
DETECTOR N
ABSORBED
PARTICLES
TRANSMITTED LIGHT
LAMP #1
DETECTOR D
SCHEMATIC VIEW (TOP VIEW)
RATIO 90° ANALYZER
M21417–4

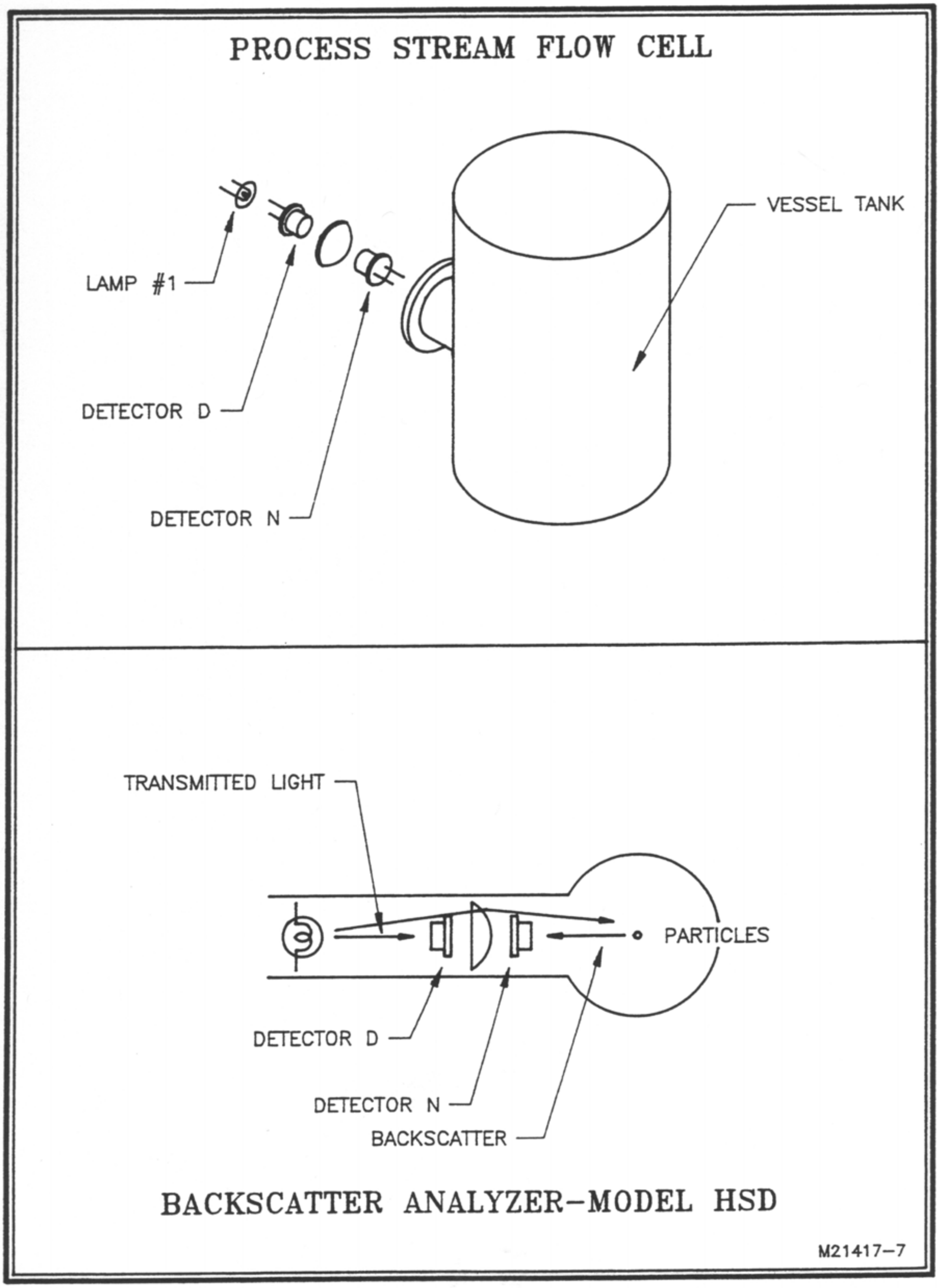

PROCESS STREAM FLOW CELL
FLOW
LAMP #1
DETECTOR N LOCATION
LAMP #2 (TEST)
DETECTOR D LOCATION
FLANGE/OR BUTT WELD
PIPE 1"–10"
SIDE SCATTERED
DETECTOR N (SIGNAL)
PARTICLES
ABSORBED
TRANSMITTED LIGHT
LAMP #1
DETECTOR D REFERENCE
BLACK BLOCKING DISK
LAMP #2 (TEST)
SCHEMATIC VIEW (TOP VIEW)
90° ANALYZER WITH MODEL HSB LIGHT TRAP
M21417–5

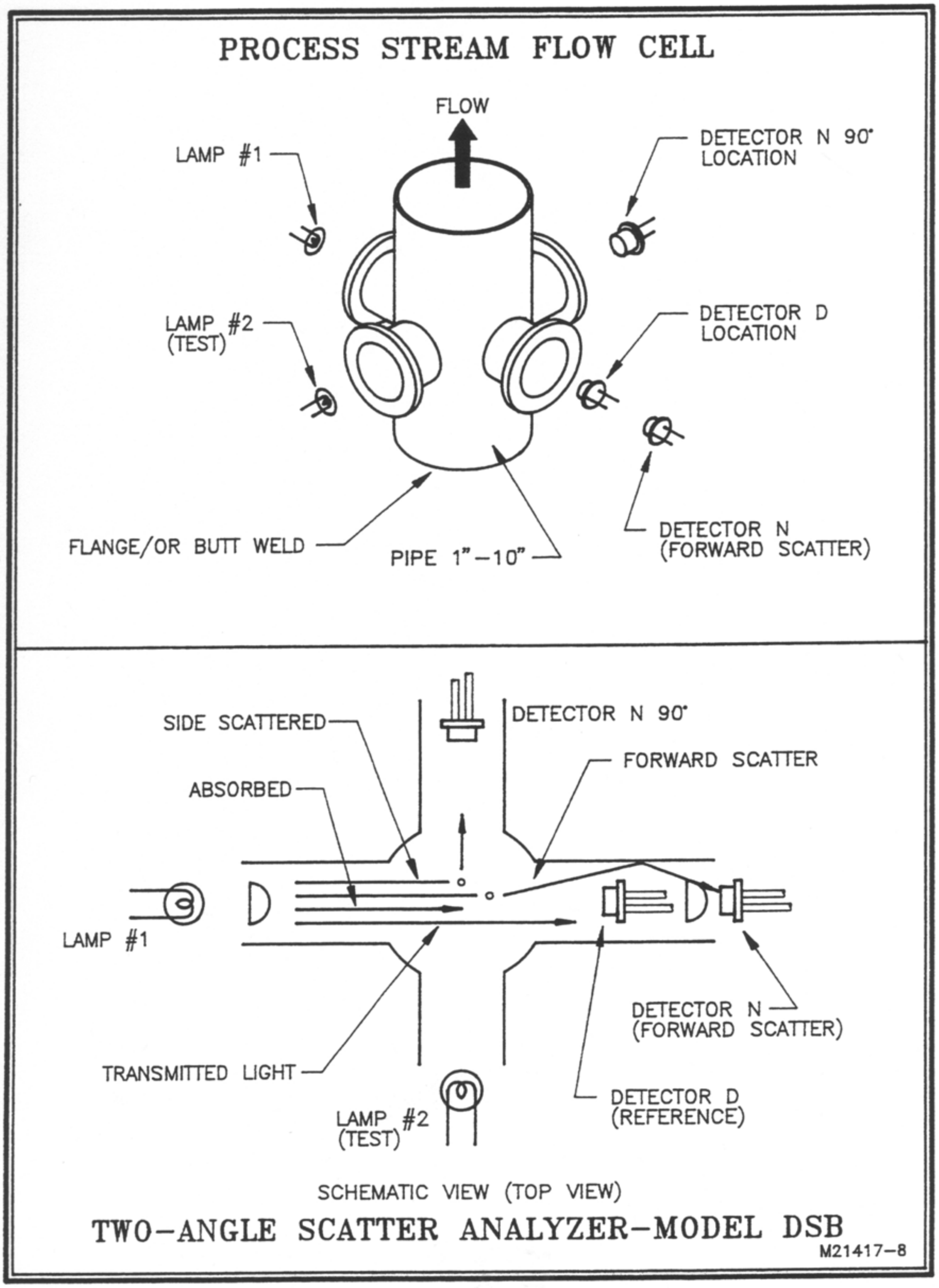


PROCESS STREAM FLOW CELL

FORWARD SCATTER ANALYZER–MODEL RS

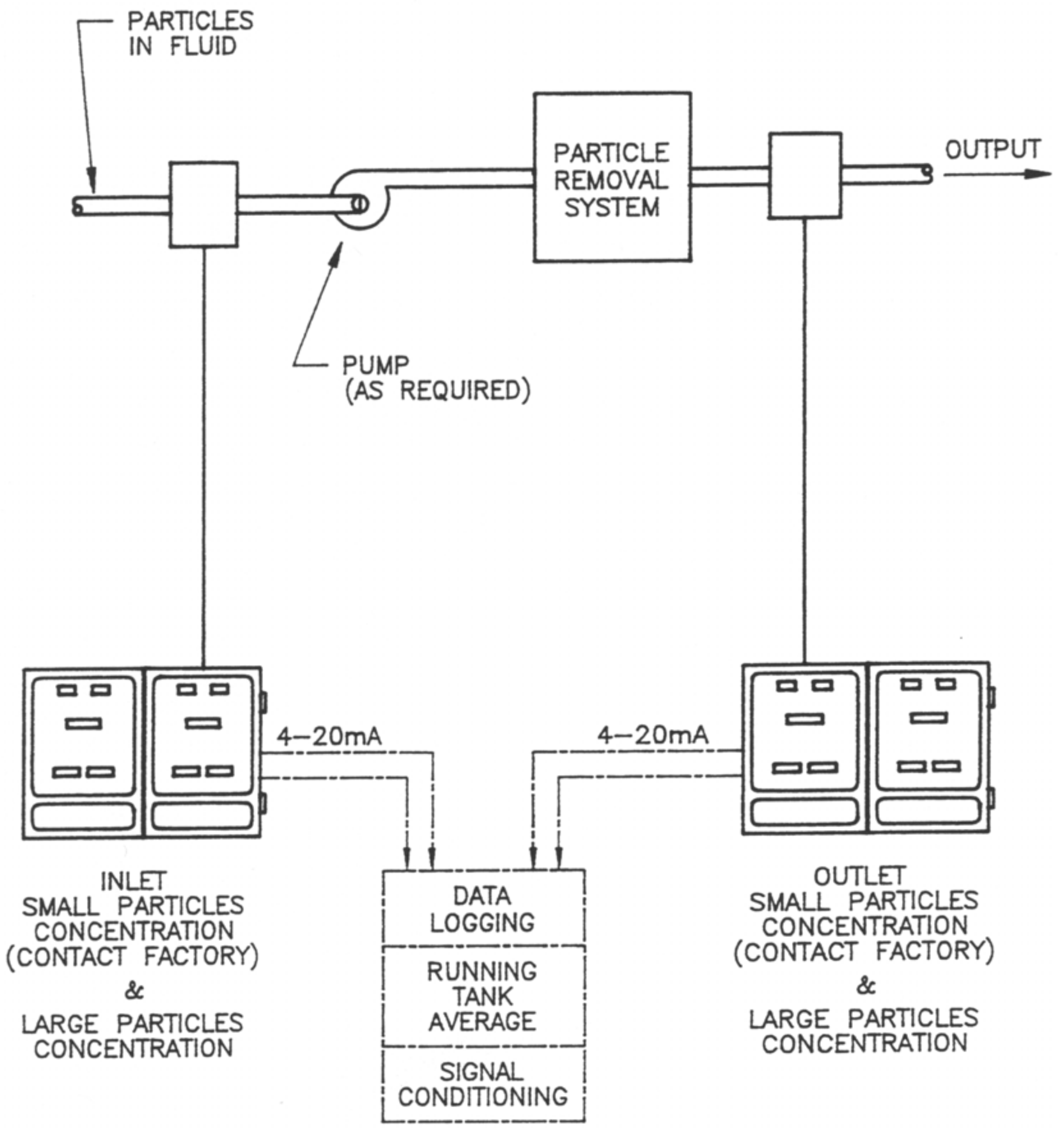
M21417–6


PROCESS STREAM FLOW CELL
LAMP #1
DETECTOR D
DETECTOR N
VESSEL TANK
TRANSMITTED LIGHT
PARTICLES
DETECTOR D
DETECTOR N
BACKSCATTER
BACKSCATTER ANALYZER–MODEL HSD
M21417–7

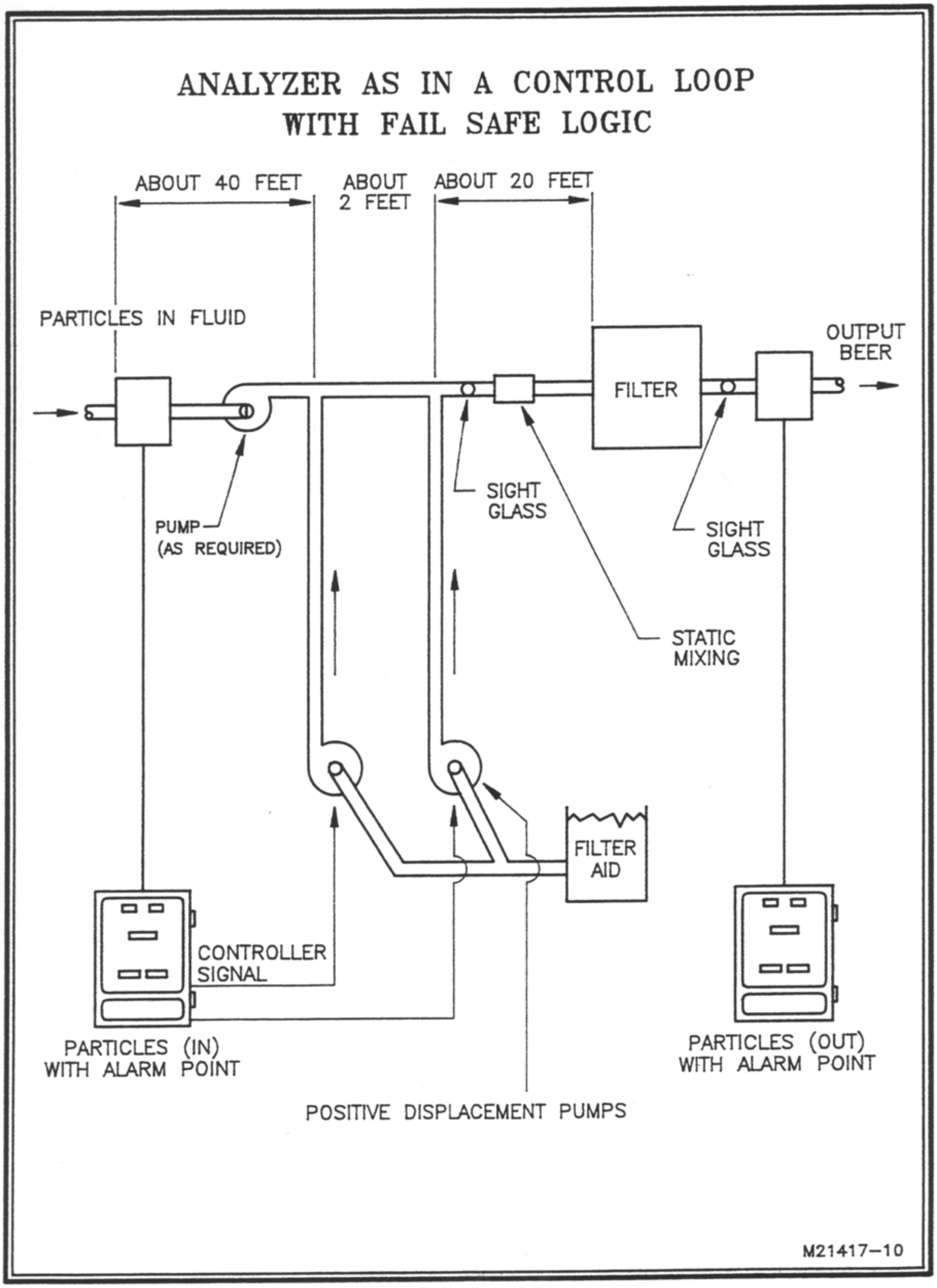


TWO–ANGLE SCATTER ANALYZER–MODEL DSB

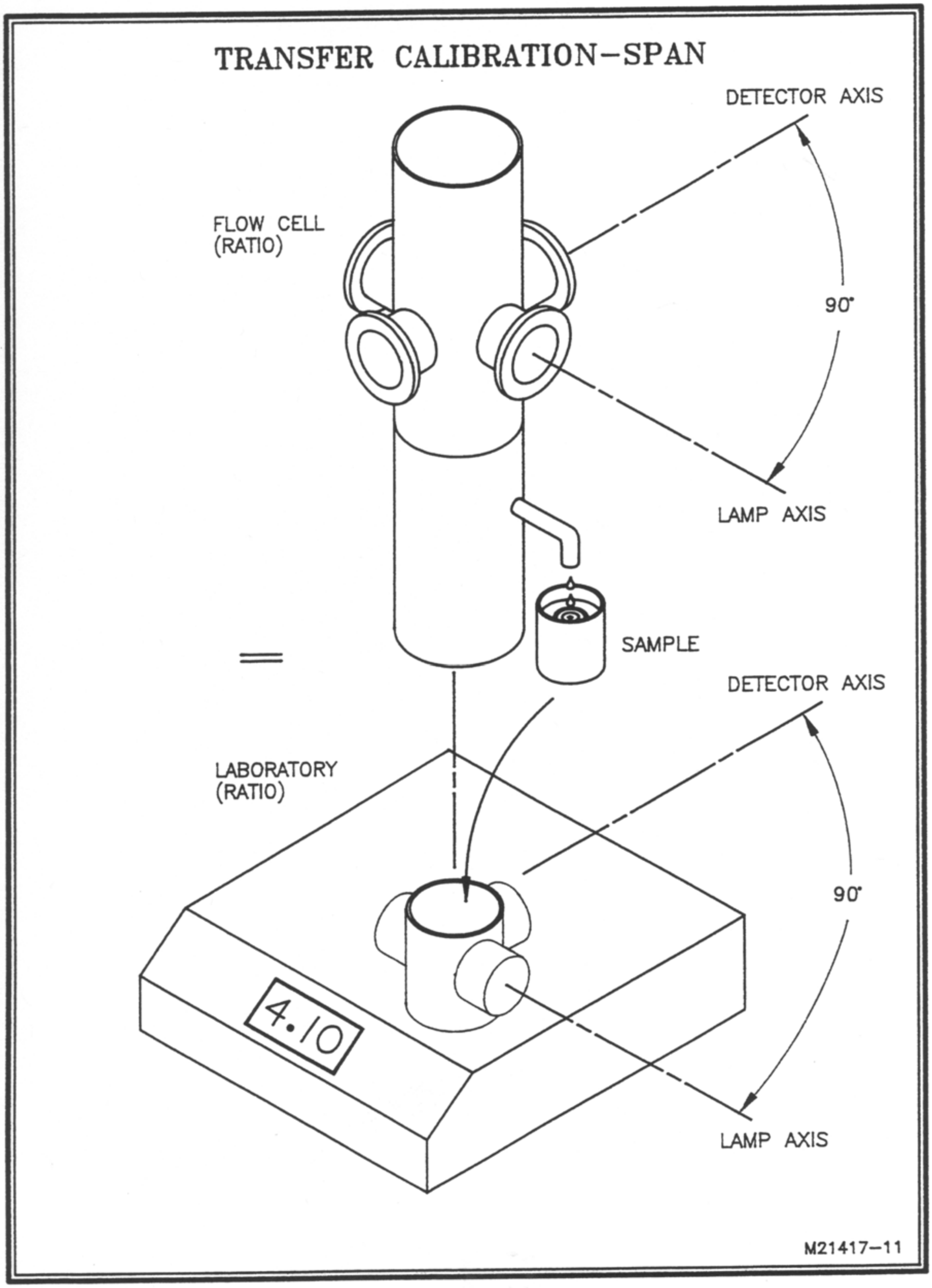
SUSPENDED SOLIDS ANALYZER AS A MONITOR



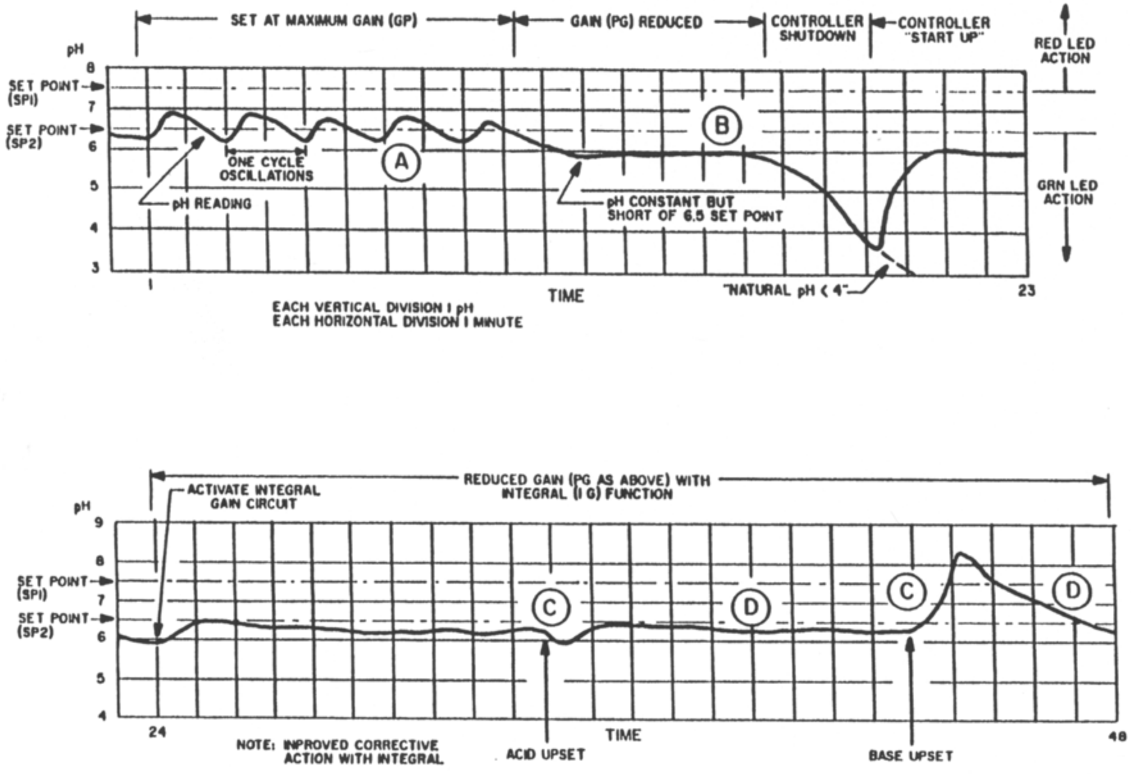
M21417–9



ANALYZER AS IN A CONTROL LOOP
WITH FAIL SAFE LOGIC


TRANSFER CALIBRATION–SPAN
DETECTOR AXIS
FLOW CELL
(RATIO)
90°
LAMP AXIS
SAMPLE
=
DETECTOR AXIS
LABORATORY
(RATIO)
90°
4.10
LAMP AXIS
M21417–11

AP-IH TUNING OF A PID CONTROLLER ACID AND BASE FEED WITH ACID FLOW



EXAMPLE OF CONTROL SYSTEM OUTPUT

NOTES:

1. ACID REAGENT (pH$_3$ H_2SO_4)/DOSING AND BASE REAGENT (pH$_{10}$NA OH)/DOSING WERE ADDED BY GRAVITY FEED AND SOLENOID VALVES.
2. PROBE MP-14 WITH INLINE INSERTION VALVE L-3P.
3. RECORDER WAS ESTERLINE ANGUS O-I r ATTACHED TO TERMINALS 5 AND 6.
4. THE AP-IH IS A PRODUCT OF McNAB INC.
   N.Y. U.S.A.
   TELEPHONE (914) 699-1616
   TELEX 701621
   TELFAX 914 699 1671

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M-21417-12

APPENDIX I

Attached is technical and installation information (*Photometric Concentration Analyzer*, A92-114) for the Model HSA family of McNab optical analyzers.

APPENDIX II

Attached is technical and installation information (*High-Sensitivity Clarity Analyzer*, A90-85A) for the Model HSB family of McNab's nephelometric optical analyzers.

APPENDIX III

Attached is technique and installation information (*Forward Scatter Particle Contamination Monitor*, A91-86) for the Model RS family of McNab's instruments.

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