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Aspirating Smoke Detection

Very sensitive and reliable fire detection through differentiation between smoke and deceptive phenomena

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The detection principle and detection performance of the newest Aspirating Smoke Detection (ASD) technology is presented in this paper. The optical dual-wavelength technology which uses blue and infrared light shows a huge advantage in detection speed and reduction of false alarms compared to other smoke detection technologies. The detection chamber of the ASD system is especially designed to be very sensitive to little amount of smoke. Using a shorter wavelength like blue light enables the detection of very small particles which are often present during flaming fires and in the incipient fire state. A combination of blue and infrared light scattering allows discrimination of smoke and dust particles by analyzing its particle size. Even in harsh environments with a high dust load an alarm will only occur when small particles are created.

Additionally a venturi bypass is used to minimize soiling of the ASD chamber. Only a small portion of the overall air stream is passed into the detection chamber. In the detection chamber minimal soiling is assured by an optimized chamber flow so that smoke and dust particles do not remain in the chamber. To assure reliable smoke detection the airflow in the pipe is continuously monitored.

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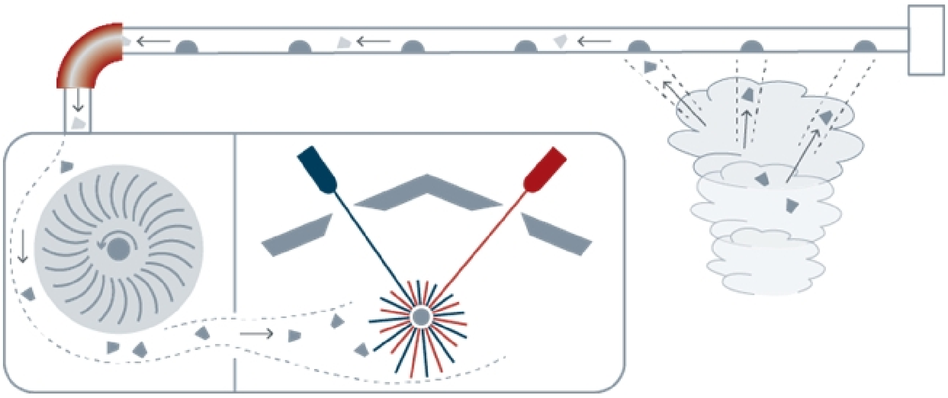


Fig. 1. An Aspirating Smoke Detector is drawing constantly air into a pipe network system so that smoke can reach the detection chamber. By using optical dual-wavelength technology very small particles are detected and discrimination between smoke and dust is possible.

Introduction to Aspirating Smoke Detection (ASD)

Motivation

Increasingly risk assessments are highlighting facilities vulnerability to the loss of high value equipment, processes, research and data. This leads to increased demand for faster and more reliable fire detection. By pushing the sensitivity of aspirating smoke detectors towards a maximum, the likelihood to false alarms increases. With common ASD technologies there is often a dissatisfactory compromise between very sensitive detection and reliable detection with low false alarm rates.

This white paper will discuss the highlights of the latest ASD technology:

- The fundamental principles of discrimination between smoke and dust using two wavelengths
- ASD performance with examples
- Chamber design for minimal soiling

How does ASD work?

A portion of air is drawn into the ASD pipe network and passed into a detection chamber (figure 1). The detection chamber is specially designed to be highly sensitive to smoke particles. Aspirating smoke detectors are up to 100 times more sensitive than traditional point type smoke detectors. The presented ASD device uses the so called optical dual-wavelength technology and combines blue and infrared light scattering so that discrimination between smoke particles and dust/steam particles is possible.

Historical background

In 1871 the physicist Lord Rayleigh wondered why the sky shines blue. He discovered that blue light is scattering stronger on small particles than long-wave light [1]. The same scattering principle was applied to the latest ASD system by using a light source with a shorter wavelength (e.g. blue light) which would detect smaller particles better than scattered light in the infrared range.

The roots of the ASD principles come from the air-quality monitoring community. The so called “Nephelometer” was firstly commercialized in 1967 to track urban air pollution using a xenon light projector to detect very small particles [2].

In 1983 the ASD pioneer Dr. M. Cole presented a first ASD prototype for forest fire detection in Australia [3]. Using the same measurement principle as the nephelometer with xenon light, it was introduced as “Very Early Smoke Detection Apparatus” to the fire market.

Later in 1996, the next generation of ASD was smaller, cheaper and had a higher sensitivity using infrared laser technology. Even if infrared laser light is more sensitive to smoke particles at 1 µm particle size, it was first not recognized that the infrared light would be less sensitive to smaller smoke aerosols under 1 µm particle size. Learning from the past using xenon light, the next generation of ASD with shorter wavelength and blue LED light became true [4].

Finally the latest ASD technology was designed and developed using a combination of blue and infrared LED technology. The sensitivity to very small particles is now recaptured using blue scattered light and at the same time infrared scattered light is used to detect big dusty particles.

Optical Dual-Wavelength Technology

Airborne particulate matter

Before introducing the optical dual-wavelength technology, the aerosol particles, which are detected by fire detectors, have to be explained more in detail.

Aerosols, also defined as particulate matter (PM), are microscopic small particles distributed in the atmosphere. For the human eye airborne particles are only visible in a group of many particles forming a cloud in the air. If we know the source of origin, the particles may fall into categories like dust, haze, fog, clouds, sand, hairspray, or smoke. Letting a device detect and categorize these particles is only possible by counting and measuring their particle size.

As depicted in figure 2, different types of particles have a range of particles size from small to large. The blue and red area is a graphical representation of a particle size distribution and explains how the amount of particles is distributed according to size (histogram). We can categorize particles like smoke, haze, soot, sea salt, in the range under 1 µm particle size. Particles like dust, sprays, carbon dust, cement dust, coarse sand or fog can be categorized as big particles over 1 µm particle size. Some airborne particles like haze or fly ash do have small and big particles

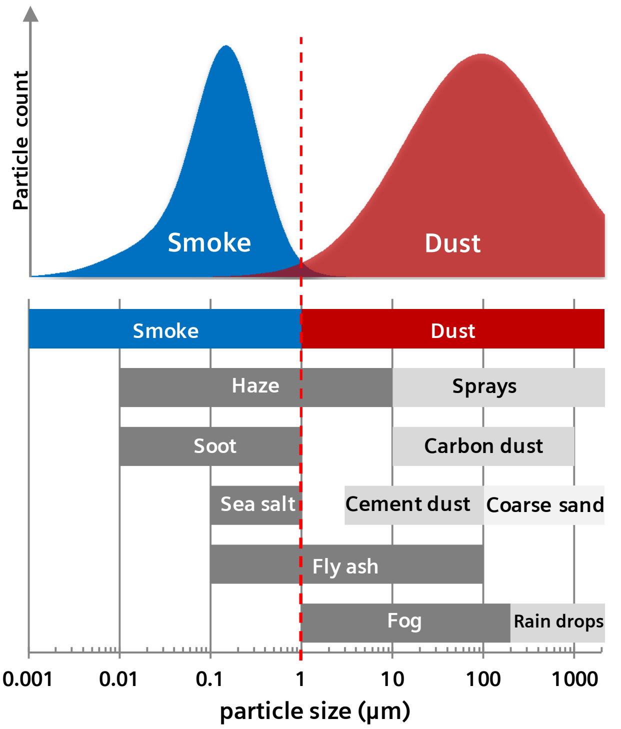


Fig. 2. Airborne particles show different types and ranges of particle sizes. The blue area shows a typical particle size distribution of smoke from a fire with a maximum particle count around 0.2 µm particle size. The red area shows a particle size distribution from dust particles with a maximum at 90 µm. (Values according to [9] [10] [11] [12])

which cannot always be discriminated at 1 µm particle size.

We can learn from figure 2 that most smoke particles are under 1 µm particle size (blue area). Looking at the red area, which represents deceptive phenomena like dust particles, it is easily seen that we can discriminate smoke particles and dust particles at around 1 µm particle size.

Advantages of using blue and infrared light scattering

As stated before, the recaptured principle of blue scattered light on particles makes it possible to detect very small smoke particles. Theoretically blue scattered light on particles is 16 times stronger than using infrared light, assuming very small particles like gases (Rayleigh scattering). But smoke particles are usually too big to be Rayleigh scatterers so that the so called Mie scattering model or more complicated models for soot aggregates apply [5]. As shown before smoke particles are in the range of 0.001 to 1 µm. Consequently blue scattered light is up to 5 times stronger than infrared scattered light [4].

Figure 3 summarizes the relative detector signal using blue and infrared scattered light for different particle sizes. It shows also that the infrared signal was normalized with the blue signal at about 1-2 µm where the particle range of most dust types start. By comparing the blue signal with the infrared signal it is now clear that bigger particles like dust do produce similar detector signals and smaller particles under 1 µm do produce a higher blue signal [4].

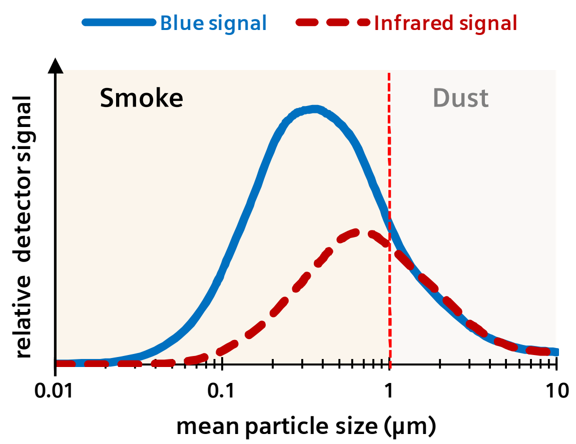


Fig. 3. By using blue and infrared light scattering the particle size is analyzed. If the mean particle size falls under 1 µm, the blue scattered signal is higher than the infrared signal. Discrimination between smoke and dust particles is possible.

Finally we can state that a theoretical approach shows the ability of discrimination of smoke and dust. In the next chapter real tests will demonstrate the performance of an ASD with optical dual-wavelength technology.

Smoke and Dust Detection

Very sensitive fire detection using blue light scattering

Comparing to other ASD technologies, the latest generation of aspirating smoke detectors can detect a more complete range of particle size by using blue and infrared LED technology. Where the usual infrared based technologies are insensitive to small smoke particles, a modern ASD uses blue scattering light to detect them in a very early fire stage.

An impressive fire detection performance is depicted in figure 4. A very sensitive response to a little amount of smoke particles out of a flame is shown. This special reduced test fire TF5A, according to EN54-20, represents a flaming fire of only 200 ml heptane in a small vessel of 10

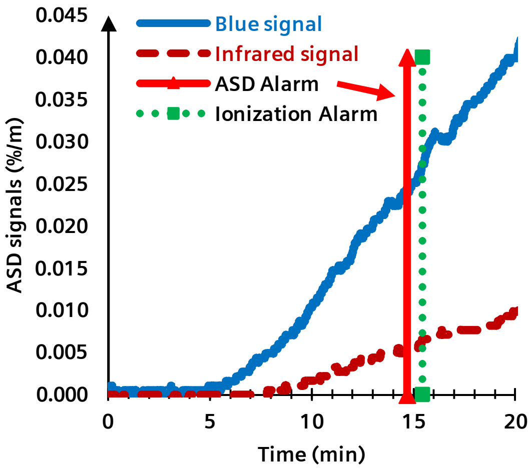


Fig. 4. Smoke detection of a reduced flaming fire (TF5A), with 10 times less smoke production than heptane fire (TF5). The ASD blue signal is 5 times stronger than the infrared signal. An alarm occurs even before the very sensitive ionization smoke detector.

cm x 10 cm x 10 cm. To produce a very little amount of smoke (10 times less than a normal TF5) a vent is blowing over the flame to dilute the generated smoke until it reaches the sampling point in a very low smoke density at the ceiling of a standard fire room (~240 m^3). No smoke can be seen by a traditional point type smoke detector or by human eye.

Looking at the blue signal the ASD shows a 5 times stronger signal as the infrared light. An alarm is generated almost at the same time as an ionization smoke detector (FM91) including 80 seconds of transport time for 60 meter pipe length with 16 holes. The alarm sensitivity was set to normal mode “automatic discrimination” which means that even an earlier alarm is possible using the “ultra sense” mode. This proofs again that by using blue scattering light very small smoke particles of a flaming fire can be detected in a very early stage. It can even beat the ionization smoke detector performance during very small fires and will still be very sensitive to smoldering fires (which an ionization smoke detector does not).

Dust detection using a combination of blue and infrared light scattering

As discussed before the infrared scattered light is best for particle sizes at 1 µm and the blue scattered light is ideal for detection of smaller particles. By normalizing the infrared signal to the blue signal at 1 µm, the comparison of both signals allows a discrimination of small and big particles.

Figure 5 shows an experiment with cement dust which causes usually false alarms for other ASD systems. Three times cement dust was injected at the end of the pipe of a SIEMENS ASD with 20 meter pipe length and 5 sampling holes. Looking at the normalized signals of blue and infrared scattering, the magnitude is very similar. There is no alarm generated even if the ASD signals are higher than in the smoke experiment shown before (figure 4). This result shows clearly that dust was detected and no alarm was generated during the event of dust injection (Operation mode: “Automatic discrimination”).

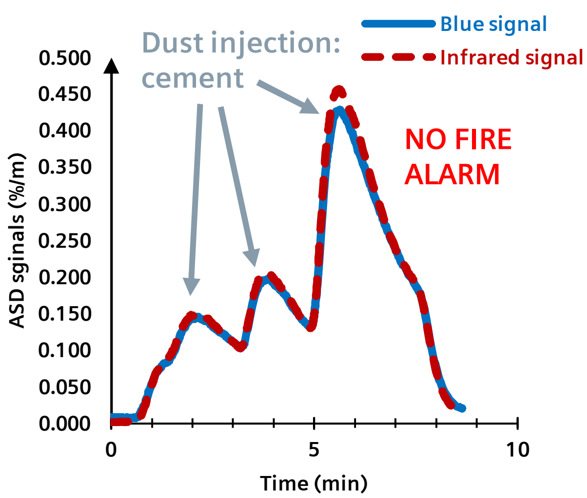


Fig. 5. Injection of cement dust into a SIEMENS ASD to simulate deceptive phenomena causing false alarms for other ASD systems. By comparing both signals and applying intelligent algorithms a false alarm was prevented.

New detection algorithms for smoke and dust/steam

To guarantee a very sensitive and reliable smoke and dust/steam detection not only a stable measurement of a little amount of aerosol is necessary but also an intelligent detection algorithm has to be implemented.

For the newest generation of SIEMENS ASD an advanced detection algorithm was invented [6]. The detection algorithm consists of two weighted alarm signals: First a smoke density signal which would give an alarm for smoke particles, second a dust/steam density signal that triggers the presents of dust/steam and gives a “dust alarm” indication at the panel.

A simplified version of the patented detection algorithm is shown in figure 6. The blue and infrared signals are transformed into a polar coordinate system, representing a vector with an angle α. Depending on the type of aerosols the vector is showing into different categories of particle sizes which makes not only discrimination of smoke and dust possible but also open and smoldering fires. Therefore the detector is able to react faster in open fire conditions which are more hazardous and require faster intervention times.

Performance test of smoke and dust discrimination

The SIEMENS ASD device FDA241 was tested with real standard test fires (EN54), non-standard test fires and deceptive phenomena like disco fog, sugar, powder, cement dust, plaster and coal dust.

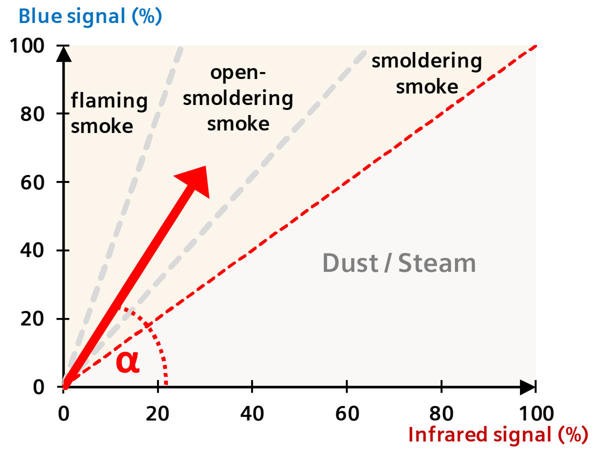


Fig. 6. Patented detection algorithm for smoke and dust/steam. A vector with an angle in a polar coordinate system allows the discrimination of smoke and dust/steam.

An extract of the performed tests is depicted in figure 7 showing the discrimination quality of the ASD. A dust detection threshold (red dotted line) is representing the boundary where dust/steam is distinguished from smoke. All deceptive phenomena were detected as dust/steam except for “ash” which has very small particles. Also some fog machines depending on the fluid could have small particles under 1 µm. As shown before in figure 2 (see ash, haze), we learned that discrimination at 1 µm is not always valid for every deceptive phenomenon. For these special cases the alarm thresholds can be adjusted to suit the specific application.

Operation modes and parameters for any application

The SIEMENS ASD FDA241 has three operation modes: “Robust”, “Automatic discrimination” and “Ultra sense”. After choosing an operation mode the alarm sensitivity can be fine tuned manually with parameter sets. Additionally every operation mode is weighing the alarm sensitivity according to the particle size which gives a better performance for smoke detection and superior false alarms immunity. A huge advantage in speed is obtained when small particle are detected in the range of flaming fires like wood fires (TF1), fuel fire (TF5) or foam fires (TF4).

The “Robust” mode with a high level of dust suppression is the ideal setting in harsh environments with deceptive phenomena (e.g. industrial areas, recycling plants and saw mills). The “Automatic discrimination” mode can be used for standard applications (e.g. huge public buildings, museums, warehouses). “Ultra sense” mode is used for applications with low dust load, where the fastest possible fire detection is needed and no deceptive phenomena are expected (e.g. Clean rooms, server rooms and manufacturing).

In some critical applications there could be smoke and dust particles at the same time. Even if there is a high amount of dust and only a little amount of smoke the ASD is on the safe side and will give an appropriate fire alarm.

Fig. 7. Performance of dust detection using the SIEMENS ASD FDA221/241. The displayed weighted signal represents a measured value for particle size. The signal increases with particles size. In general, flaming fires like woods (TF1), foams (TF4) or fuels (TF5) have small smoke particles that can be distinguished from dust and steam.

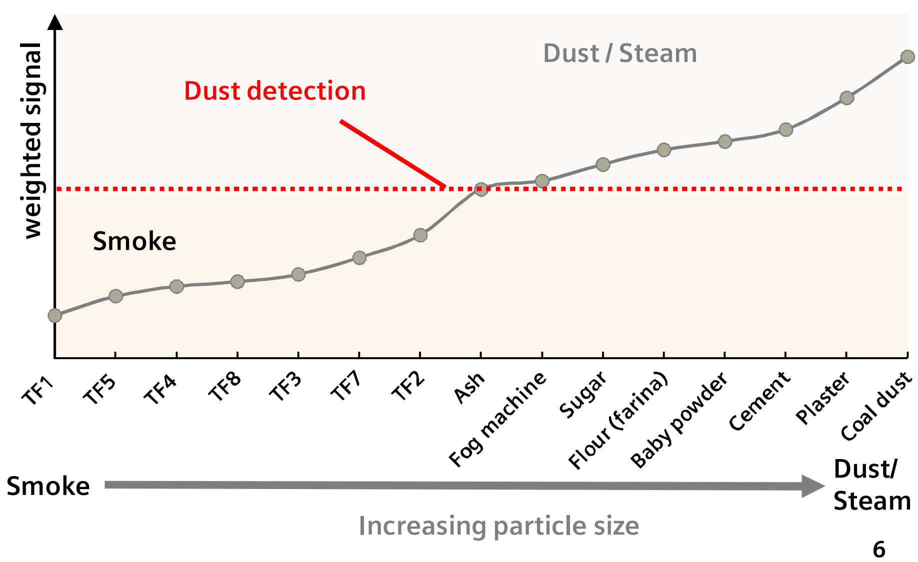
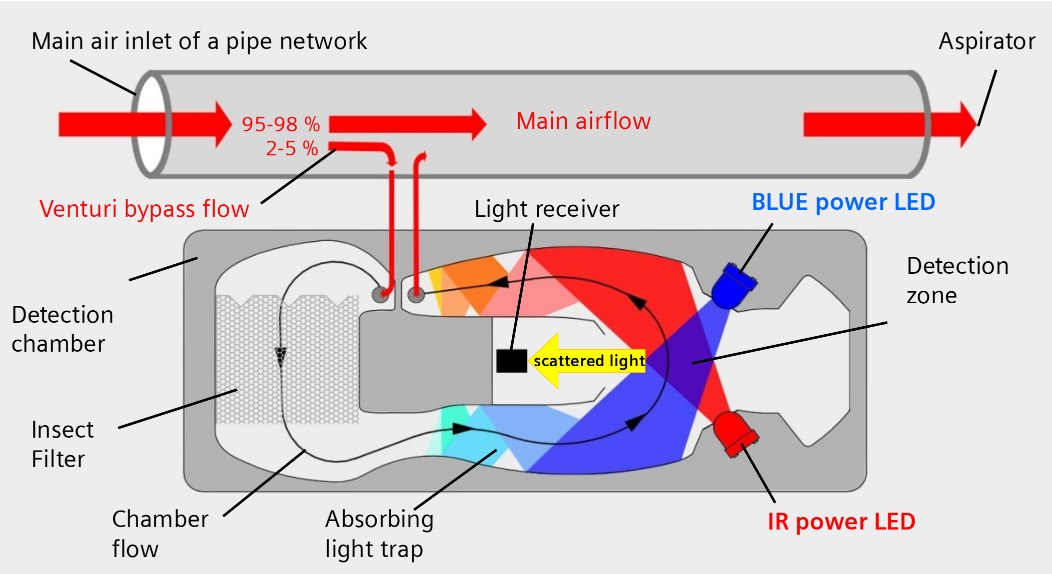


Fig. 8. Overview and function of the aerodynamic design of the SIEMENS ASD detection chamber. A venturi bypass is forcing only a small portion of air into the detection chamber. Smoke and dust particles are detected by a high sensitive optical measurement setup. An optimized chamber flow assures no separation of smoke and dust particles.



ASD Design

Patented detection chamber

The SIEMENS ASD detection chamber was designed for very high sensitive aerosol monitoring. As shown in figure 8 the detection chamber uses two high-power LED projectors with blue and infrared light to measure very little amount of airborne particles. In the detection zone particles are illuminated and a very small portion of light is scattered and focused in direction of a light receiver. The received light can be one billion times weaker than the projector light itself so that the reflecting walls, irises and other optical devices have to guide the light to assure the lowest possible signal-to-noise ratio at the receiver [7].

After passing the detection zone, the emitted light from the projectors are absorbed in two light traps like it is known from traditional point type smoke detector with a labyrinth. This avoids that the weak scattered light is flooded by the emitted projector light. The blue power LED technology is preferred because blue laser technology is not stable enough for elevated temperatures (> 20°C).

The ASD chamber in figure 8 shows that only a very small portion of 2-5 % air ("Venturi bypass flow") from the main pipe flow is passed into the detector chamber. The so called "Venturi effect" at the chamber inlet allows a flushing of the complete detection chamber in a short time while minimum aspirator energy is used to maintain a good smoke transport time in the pipe network.

Aerodynamic design with minimal soiling

To extend the lifetime of the ASD chamber optics and to minimize soiling, the complete chamber aerodynamic performance was simulated and optimized. This was achieved by guiding the chamber flow such that turbulence is minimized and laminar flow regimes apply (Reynolds numbers from 100 to 200). Changes in airflow velocity and direction are only very smoothly affecting the chamber flow (see figure 8). For these reasons, dust particles tend to remain entrained within the air and are carried all the way to the exit. There is insufficient momentum passed to the dust particles to allow the dust to become separated from the airflow by centrifugal forces. Thus the rate of soiling is reduced and dust is not accumulated in the chamber.

Even though only 2-5 % of dust is entering the detection chamber a coarse insect filter with large pore size and a long depth is included to prevent big particles to disturb the detection chamber. There is no risk of removing smoke or too much dust. The latter will be anyway detected and discriminated by the optical dual-wavelength technology.

Aspirator and flow control

The aspirator draws air through a pipe up to 60 meters length where a large pressure drop is observed along the pipe. The aspirator was designed in such a way that relatively high pressures at low flow rates are assured. The complete ASD system was designed for low power operation and maximum efficiency. Airflow may be anywhere between 15 to 65 liter/min (depending on the pipe configuration) while only consuming 3.5 Watt of energy.

Last but not least, the airflow is safely monitored by an airflow sensor and a temperature sensor, located in the ASD chamber. As a result of increasing temperature in the pipes, the air density decreases causing a lower volume air flow. By measuring the air temperature in the chamber, the deviation in volume air flow is corrected by increasing or decreasing the aspirator speed accordingly. Consequently, the volume air flow remains stable during temperature changes from -20 to +60 °C due to the patented temperature compensation algorithm [8]. Therefore, a reliable flow control is possible with a "flow alarm" showing when the flow is blocked or interrupted.

Summary and Conclusion

In this paper the basic detection principle and the detection performance of the latest ASD technology using blue and infrared scattering light are presented.

Particulate matter, respectively microscopic small airborne particles like smokes, dusts or steams have different particle size ranges. They can be roughly categorized and discriminated into “smoke” particles under 1 µm and “dust” particles over 1 µm.

Consequently the advantages of optical dual-wavelength technology apply using blue and infrared scattered light to detect small and big particles at the same time. A combination of blue and infrared scattered light is used to detect small particles from 0.001 to 1 µm particle size and big particles over 1 µm particle size. The shorter blue wavelength compared to traditional infrared light is scattering up to 5 times stronger while very small smoke particles are present. Discrimination between smoke and dust can be achieved by knowing this effect.

The performance of the presented ASD showed a huge increase of detection speed during a diluted flaming fire (TF5A) where the alarm speed, even with the largest sampling-pipe length, was comparable to the well known ionization smoke detectors which are ideal for very sensitive detection of small smoke particles and flaming fires. A second experiment showed the injections of cement dust into the ASD pipe system. A “dust alarm” was displayed at the panel indicating clearly the experiment was unambiguously detected as dust.

A summary of real standard fire tests, non standard fire tests and deceptive phenomena like disco fog, sugar, powder or cement dust showed that the patented algorithms are well performing. Only flying ash and some fogs are prone to false alarms. For these cases the alarm sensitivity has to be adjusted to the specific application.

The patented ASD chamber was especially designed for high sensitive aerosol monitoring with minimal soiling. Only few percent of the overall air stream is passed into the detection chamber using a venturi bypass. As a result, only a portion of smoke and a portion of dust are reaching the detection chamber. Thus 20 to 50 times less soiling is achieved compared to other ASD systems exposed to 100 % flow of the overall air stream.

Further, soiling is avoided by implementing an optimized aerodynamic design of the detection chamber with very low Reynolds numbers. Turbulence is minimized and a laminar flow streams smoothly along the detection chamber walls which are guiding smoke and dust particles without separation to the exit.

Finally, the airflow in the ASD system is maintained by an efficient low-power aspirator and controlled with an airflow sensor and a temperature sensor. The flow is adjusted and maintained via a patented temperature compensation algorithm for a wider operation range from -20 to +60°C.

In a few words, using the optical dual-wavelength technology makes the ASD very sensitive for smoke detection and at the same time robust against false alarms. The special designed detection chamber minimizes soiling and extends lifetime and service intervals.

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