Miljø- og Fødevareministeriet
Miljøstyrelsen

Dust and particulate measurement in wet-gasses and for ex-areas

- A MUDP project

MUDP-rapport

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Indhold

1. Introduction

This reports aim is to describe Green Instruments (GI) development of dust and smoke meter for Particulates Monitoring (PM) in wet gases in Explosive Atmospheres (Ex) areas. The report will include documentation of challenges, decisions and status for the process.
The project was initiated and supported by the Environment -and Ministry of Food program, MUDP.
The project was started January 1, 2016 and completed by October 2018. Green Instruments will continue development of the wet-gas meter based on the project results.

2. Background

It has long been known that there are health problems associated with particulate air pollution. As the land-based particle pollution over the years steadily has been reduced, an increased share of particulate emissions to the atmosphere comes from diesel-powered ships. Currently there are limited regulations and only some regional limits for particulate matter from ships in some parts of the United States.

Manufacturers of marine engines use Particulate Mass (PM) for the measurement of particulate emissions, but IMO has since 2013 negotiated possible introduce of limits for Black Carbon (BC). These negotiations have not yet resulted in proposals, but any requirements for BC limits is expected to correlate with requirements for particulate matter (PM).

Because of regional and global environmental requirements for using low sulfur fuel or reduction of SO2 and particulate emission pollution, many vessels (especially cruise ships) installed air pollution control (called "Scrubber"). The flue gas cleaning technology is often based on washing/rinsing the flue gas to reduce SO2 and particulate emissions, thereby creating wet gases which existing measurement technology, in the chimney, not can handle.

The installation of wet-gas scrubber’s onboard ships has created a demand for equipment which can handle and measure the exact discharge of particulate matter in wet gasses. Thus, there is a need to development a new wet gas measurement equipment, so the actual particulate emission can be measured and documented.

With the development of the new wet-gas meter the ship-owners can in the future document emission compliance, and their own targets for reducing particle emissions and pollution.

In addition to the marine market the offshore sector has a major need to measure particulate emissions and mist. Development and marketing of wet gas-meters to the offshore industry requires the product to be ATEX (ATmosphère EXplosive) approved, which provides additional challenges related to the development of the new wet gas meter. In the marine sector, there are also customers requiring ATEX approved equipment - and especially the owners who use gas-powered ships.

3. Objectives, goals and success criteria – the expected solution

The projects aim is to develop a unique optical measuring system that can measure the concentration of soot and dust in wet gases, as well as in areas where flammable liquids, oil mists, gases or dusts occur, and could ignite and create an explosion.
The measuring system will differ from known solutions by providing more reliable data in accordance with the regulations at a significantly lower cost than existing solutions.

The new measurement system will be more robust, reliable and easy to use. The unique technology makes it possible to perform real-time measurements in explosive atmospheres (Ex areas) and provide data for process control and reporting.

The measuring system can be used in both new and existing installations. The measuring system will create increased value for customers and contribute to safer and more reliable data for the measurement of particles in wet gases and in particular contribute to a global reduction of significant air pollution.

Success criteria for the project is to develop a unique product targeted marine and offshore industry, approved for use in the marine sector (certified) and ATEX and IECEx approved.

Goals and success criteria for the project can be summarized in table 1, as follows:

TABLE 1. Goal and success criteria

Project goal	Success criteria
Develop and test Green Instruments G16 / G26 laser technology in relation to wet gasses	The green laser technology can be used for wet gases
Develop and test the optimal drying process which contributes to reliable measurement of wet gasses.	The drying process can be used in the new measuring system
Develop a product that meets the requirements of ATEX directive	The end product can be used in EX areas and meet the ATEX directive for both the marine, offshore and industrial markets.
Implementation of market test. The product works as intended.	To test the system aboard a selected ship after a flue gas scrubber (wet gas scrubber) and provide real time data under extreme conditions

4. Possibilities and limitation

It is anticipated that the requirements for PM measurement and reporting will increase in the coming years in both Safe and EX areas. With the ambitions to measure PM and mist in EX areas it opens up for new potential markets and it is considered an important forward move for Green Instruments.

Accurate measurements of particulates in wet waste gases after air-pollution cleaning systems makes it possible to measure the effect of the system. If/when limit-values for particulate emissions is agreed by IMO, the majorities of the ship owners who use air pollution control, need a reliable measuring device to measure particle emissions.

Green Instruments's wet gas meter will perform measurements with high accuracy and provide a reporting base for precise documentation that limits are respected. Already today there is an interest from several customers to buy wet gas meters, since they want to be able to document the reduced particle emissions when actively using pollution cleaning systems like scrubbers and filters.

An accurate measurement of particle emissions allows ship owners to compare the real emissions to the companies' own internal targets for emissions of environmentally harmful substances and give owners the opportunity to give the company a green profile.

It is expected that more and more companies in the future will strive for a green profile. This applies specially to the cruise-shipping industry, who in general wants to be "green" and has a customer base that appreciates that the environmental impact is minimized and they are not bothered by air pollutants during the voyage.

There are also local authorities who are very focused on particulate emission - this is particularly true in California, where smog is already a major problem and in Alaska, where black carbon causes a faster melting of the ice with major environmental consequences.

By adhering to the local authorities' requirements and comply with own internal ambitious environmental goals and demonstrate this by a reliable measurement, the ship owners will support a green profile.

5. General Emission Monitoring

Particulate emission monitoring is a challenging technical field, not only because of the application specific accuracy and performance of particulate emission monitors, but also due to the harsh environments including wet gasses in which they must continuously operate.

When the flue gas is below dew point it is not possible to use an in-situ PM CEMS, since water droplets and condensed steam give an interfering response in the CEM (water droplets absorbs and scatter light similarly to particulate matter). Hence, it is not possible to differentiate in an in-situ PM CEMS between the signal coming from particulate matter and water.

An extractive approach is therefore required to measure PM continuously in a wet stack. This necessitates the use of techniques which do not suffer interference from water or work on the basis of evaporating the water ahead of measurement with a ‘dry’ light transmission or scattering Continues Emission Monitoring System (CEMS).

As illustrated in table 2 the core techniques used for continuous monitoring of particulate are as follows:

- Light attenuation (Transmisiometry): In which the amount of light absorbed by particles crossing a light beam is measured and correlated to dust concentration. In Opacity/Extinction instruments the amount of light reduction is measured directly whereas in Ratiometric Opacity the ratio of the amount of light variation (flicker) to the transmitted light is measured.

- Light scattering: in which the amount of light scattered (reflected) by the particles in a specific direction is measured. Forward, side and back scatter are a function of the angle of scattered light that is measured by the detector. Light scattering techniques (especially forward scatter) are capable of measuring dust concentrations several magnitudes smaller than that measured by light attenuation techniques.

- Probe Electrification: in which the electrical current produced by particles interacting with a grounded rod protruding across the stack/duct is measured and correlated to dust concentration. Charge induction (AC Tribolectric and ElectroDynamic) and DC Triboelectric instruments are types of probe electrification devices in which different signal and current analysis are performed.

One of the fundamental issues in obtaining good results from particulate instruments is to ensure that the instrument is fit for purpose for the intended application. This means that the instrument 1) has a stable, reliable response which can be directly correlated to dust concentration with limited cross interference from likely changes in process or flue gas conditions. 2) can operate long term in the application without the need for maintenance or cleaning. 3) sufficient resolution for the intended application. The certification range is normally in mg/m3 for the instrument which is the lowest dust range at which the instrument will still meet the performance standards. The minimum detection level of the instrument should also be considered in relation to the normal operating condition of the plant to ensure a meaningful stable response from the instrument at normal plant conditions which can then be calibrated.

6. The way forward

Based on our current G16 laser technology, related technologies and what is already viable on the market within the wet-gas measurements as well as Ex protection, the projects focus was on the following four (4) areas:
a) Sample system (probe and sample system)
b) The measurement system (Measuring System)
c) Management and control system (Controller and user interface)
d) Ex certification according to ATEX and IecEx (Ex certification)

7. Technology overview and decisions

In table 2, the most common smoke measurement technologies are illustrated, based on concentration rages. This project, based on our green laser technology with wavelength of about 520 nm. Opacity (technology 4) and scattering (technology 5) was selected for this project.

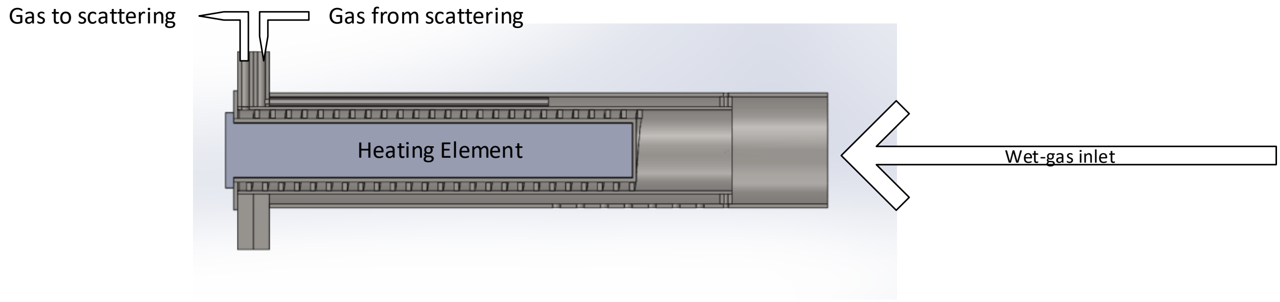
TABLE 2. Measuring technology overview

Technology	Measuring technology	Concentration min. mg/mg3	Concentration max. mg/mg3	Velocity dependent
1	Probe electrification (AC)	0,1	1000	No (8-20 m/s
2	Probe electrification (AC and DC)	1	1000	Yes
3	Transmissionmetry rationmtric	10	1000	No
4	Transmissometer transmission/opacity	20	1000	No
5	Scattered light (forward)	< 1	300	No
6	Scattered light (back/side)	10	500	No

Note: Realistic detection levels for our gas analyzer will be between 5-20 mg/mg3 to 200 mg/mg3

7.1 Probe and sample system

Based on Transmission (Opacity) and Scattered light (Scattering), is was decided to implement an extraction system for optimal dry condition of the sample gas.
Initial test installation at Teknologisk Institut with direct On-stack stack opacity measurement on wet-gasses revealed limit measurement errors due to water absorption in the green laser spectrum band (520 nm visible light). However, in certain load areas and high humidity some sensitivity to water droplets were noted and supporting the need for extraction and sample conditioning.
For the opacity system, an external measurement chamber with gas inlet demister and heating module for wet process gasses was designed, see figure 1.
For the Scattering system, the initial design was based on a heated probe with sufficient capacity to secure evaporation of water droplets and condensate above the dew point. As the sample gasses passes into a vaporizing chamber in the probe the centrifugal motion of the flue gas against the heated (220’C) cylindrical walls removes any water droplets or vapor and brings the gas above dew point.



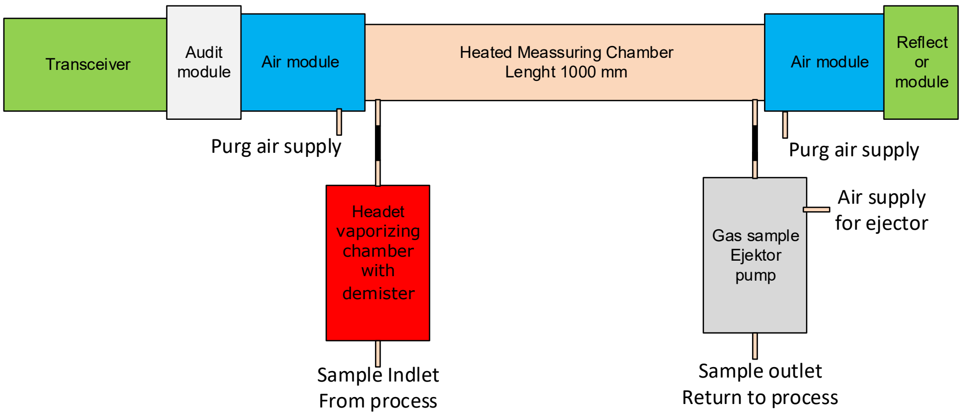
FIGUR 1. Heated probe with vaporizing chamber for scattering
The transport of the extracted gas from probe to the measuring system will use an air driven ejector pump.

7.2 Measuring system

Two measuring system were implemented based on our green laser technology:

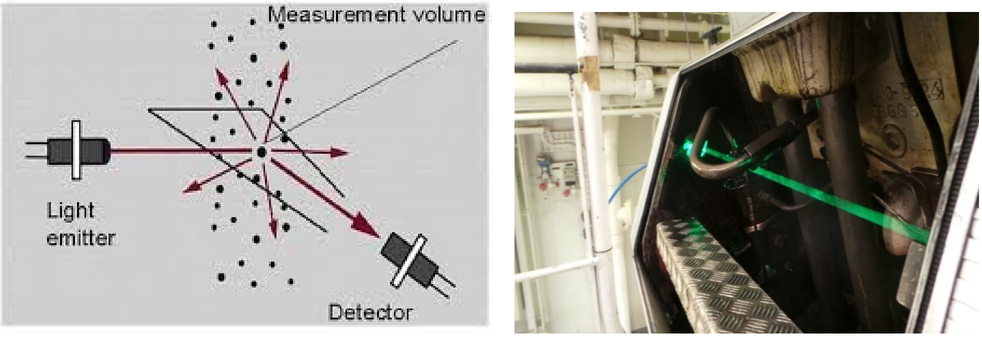
1. Optical transmission or opacity of emission.
2. Optical light scattering from particles emission.

For both measurement systems the sample is conditioned and transported undiluted to a heated measuring chambers where particle detection takes place, see figure 2.
The opacity emission detection system consists of an optical transmitter/receiver unit (transceiver), attached to one side of a 1 m long measuring chamber. On the other side of the measuring chamber, a reflector unit is mounted. The transceiver contains a light source, photo detectors and controller. The reflector unit consists of retroreflector built into housing and mounting arrangements.
Both the transceiver and reflector units are arranged with a purge air module for keeping the optical windows free of contamination from the process gas. The purge air supplied shall be clean and free from particles and adjusted to a flow rate of about 10 L/minutes.
For control and verification, an audit module is placed between the transceiver and air module where various opacity levels can be simulated by inserting calibrated audit filters.



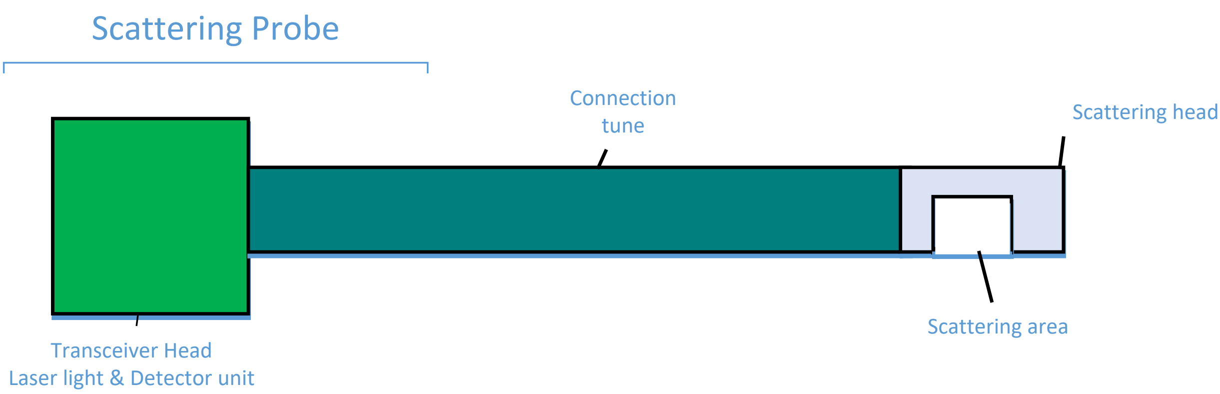
FIGUR 2. Measuring system for optical transmission (opacity meter)

For small particle concentrations below 20 mg/m3 the measuring system was based on forward light scattering. A projected laser beam of modulated light (visible range - wavelength approx. 520 nm) hits the particles in the gas flow passing the beam. The light scattered by the particles is recorded by a highly sensitive detector which is positioned in an angle of approx. 15° to the beam axis, see below figure 3 and photo of scattered light from our green laser.

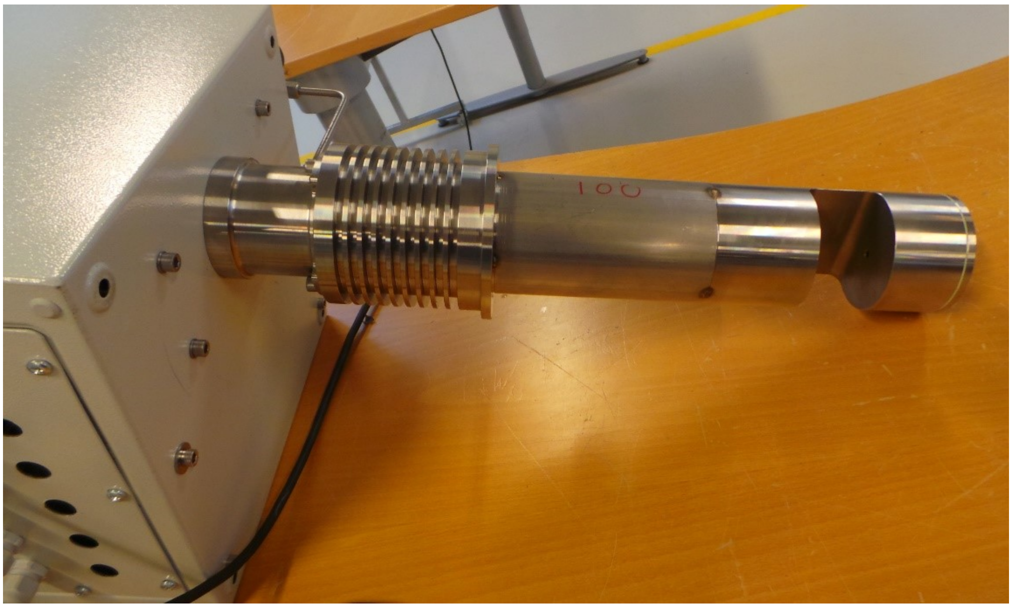


FIGUR 3. The detected/seen light signal represents concentration of particulates in the air/gas.

With the ambition to end up with a unique wet gas measuring system, our market research has provided inside to what technical solution there already are available and what possible we may have for product protection including IPR.
After an evaluation of our options and tests of probe, sample and measuring systems the opacity and scattering system was both be simplified based on our current laser technology. This design allows all critical parts to be located in the Transceiver Head outside the process in a suitable low temperature atmosphere.
The scattering head and transceiver head is connected via a tube which make the system adaptable to the actual process requirements, see scattering probe design figure 4 and photo of the scattering probe figure 5.

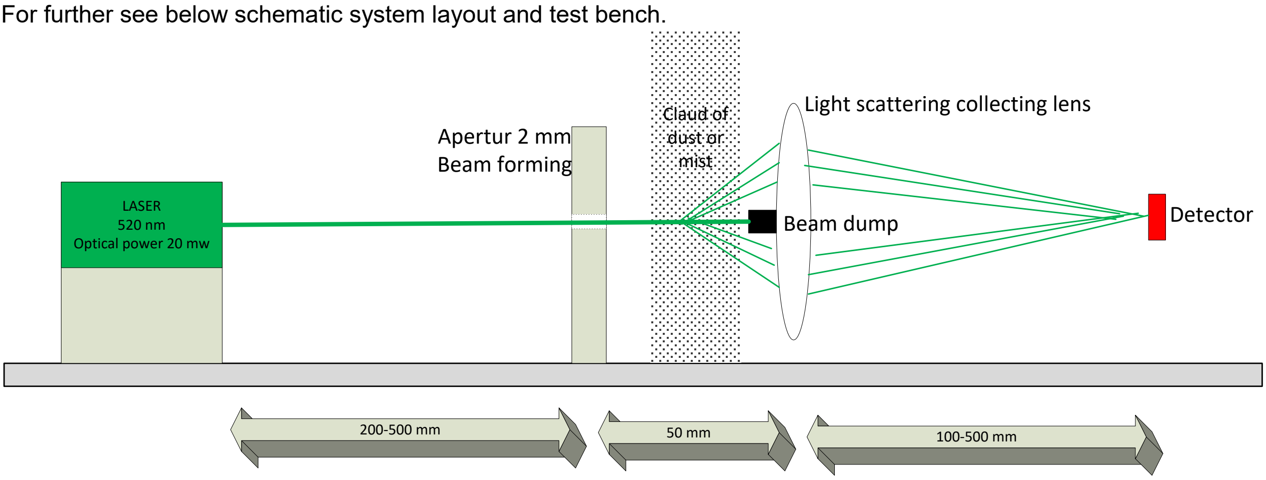


FIGUR 4. Scattering probe with connection tube.

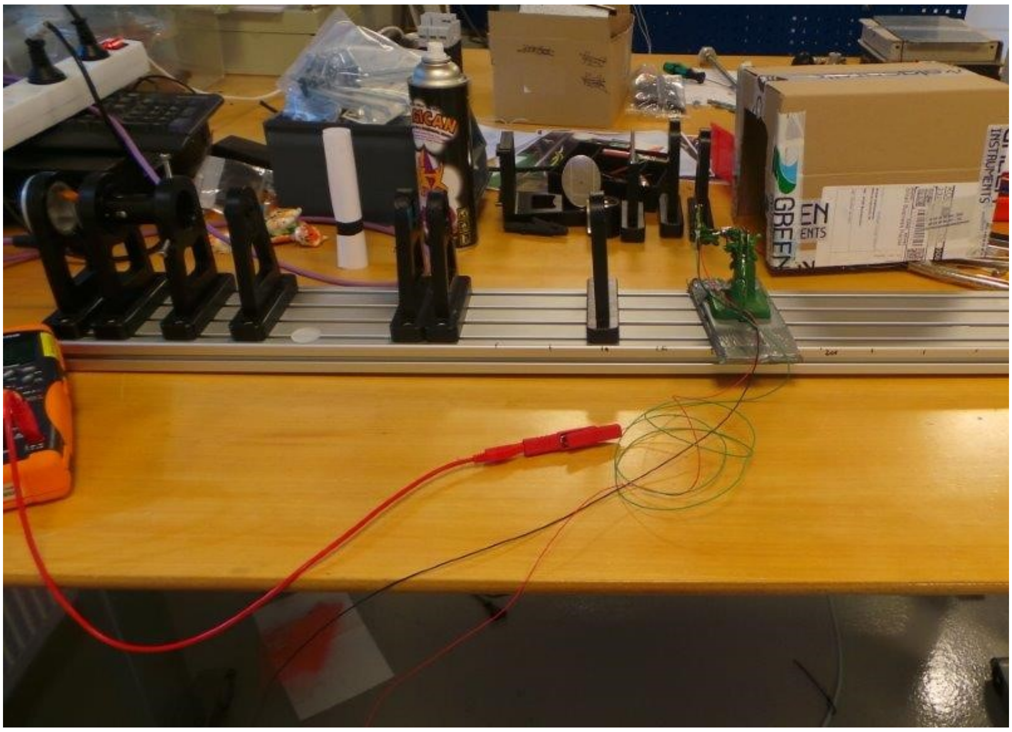


FIGUR 5. Scattering Probe with control box

The laser beam will be transmitted from the Transceiver head and returned back in the scattering head and into the scattering area where it finally will be trapped so that only the scattering light will be collected and returned to the Transceiver head, see figure 6.
For preliminary tests a simple inline system, see figure 7, was arranged with a 2mm laser beam. The laser beam was initially trapped or dumped right before the collecting lens which later was changed with the collecting lens moved about 100 mm away from the scattering area in order to collect good scattering signals from particles between 500 nm to 5 my.
For further see below schematic system layout and test bench.



FIGUR 6. Schematic arrangement of in-line scattering system.



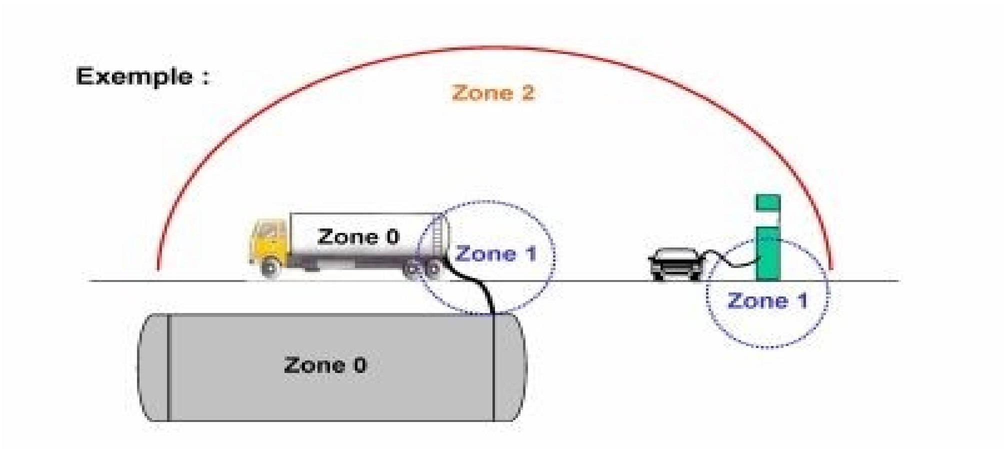
FIGUR 7. Test bench - simple in-line test system where lens location and scattering forms can be tested and optimized.

7.3 Control and user interface

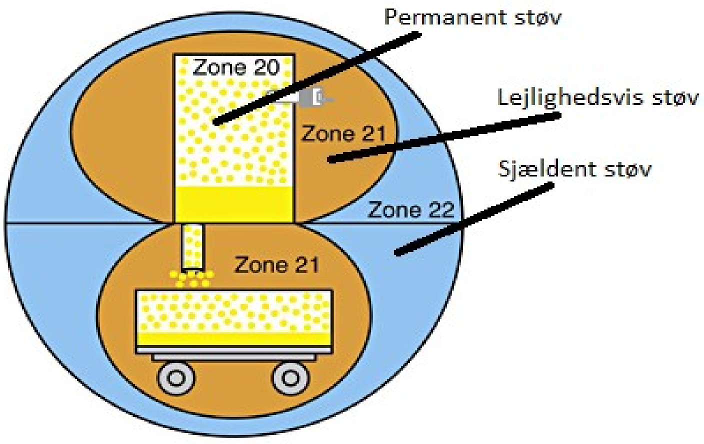
The Control and interface unit, was based on our existing hardware HMI platforms (Idec/Schneider) upgraded with required software.

7.4 Ex certification

The initial investigation points in the direction of Zone 0 for gas and 21 for combustible dust. However, after further market studies this high protection level appeared not large enough for us to justify the additional cost with Zone 0 and 20 compared with zone 1 and 21, see figures 8 and 9.



FIGUR 8 Zone classification



FIGUR 9. Zone classification

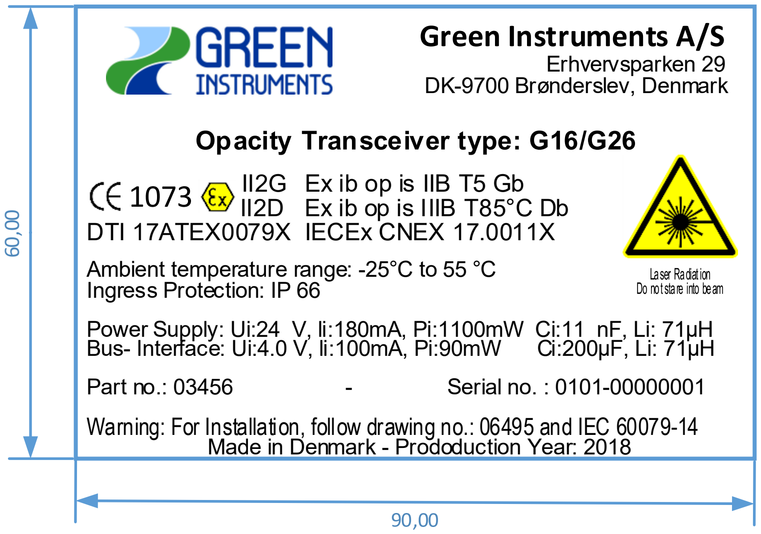
TABEL 3. Zone classification for gas and dust

ATEX category	Substance	Protection level (EPL)	Zone	Intrinsically way of protection	EPL
1 G	Gas	Very high	Zone 0	Ia	Ga
2 G	**Gas**	**High**	**Zone 1**	**Ia or ib**	**Gb**
3 G	Gas	Normal	Zone 2	Ia or ib	Gc
1 D	Dust	Very high	Zone 20	Ia	Da
2 D	**Dust**	**High**	**Zone 21**	**Ia or ib**	**Db**
3 D	Dust	Normal	Zone 22	Ia or ib	Dc

Therefore, it order to move on it was decided to go with protection level according to Zone 1 for gasses and 21 for combustible dust based on both ATEX 2014/34/EU and IECEX product certification in accordance with the following standards:

IEC 60079-0;2011, IEC 60079-11:2011 and IEC 60079-28:2015

EN 60079-0;2012 incl. A12, EN 60079-11:2012 and EN 60079-28:2015



FIGUR 10. ATEX – IECEx official label 90 x 60 mm from Green Instruments A/S

With reference to figure 10 the following information are provided as part of the labeling of the Ex certification and compliance with ATEX and IECEx requirements:

1. Name and address of the manufacturer: Green Instruments A/S, Erhvervsparken 29, DK-9700 Broenderslev, Denmark, Phone: +4596454500 Fax.: +45964501, Website: www.greeninstruments.com

2. Type of Instrument: Opacity Meter - G16/G26 Transceiver

3. CE marking and marking for explosion protection: Gas: II 2 G Ex ib op is IIB T6 Gb
4. Dust: II 2 G Ex ib op is IIIB T85°C Db (Suitable for Use in Zone 1 Gas and Dust applications zone 21) ATEX and IECEX certification numbers: ATEX: DTI 17ATEX0079X and IECEX: CNEX 17.00011X.
5. The meanings of the ATEX and IECEx code are as follows:

- II: Group for surface areas (not mines)
- 2: ATEX Category (2 suitable for gas zone 1 and dust zone 21)
- G: Gas (dangerous media)
- D: Dust (dangerous media)
- Ex ib: Intrinsic safety, protection level [b]
- op is: Inherently safe optical radiation
- IIB: Gas group (a typical gas is ethylene)
- IIIB: Non-conductive Dust group
- T5: Temperature of the Transceiver class
- Gb/Db: Equipment Protection Level (EPL)
- Operating ambient temperature range 0°C to 55ºC

6. Housing protection level: IP66 rating
7. Intrinsic Safety (IS) data for the G16/G26 Transceiver and requirements to the barrier:

- IS-Data power supply: Ui:24 V, Ii:180 mA, Pi:1100 mW, Ci: 11 nF, Li 71µH
- Bus interface-Data power supply: Ui:4.0 V, Ii:100 mA, Pi:90 mW, Ci: 200µF, Li 71µH

8. The serial number of the device.

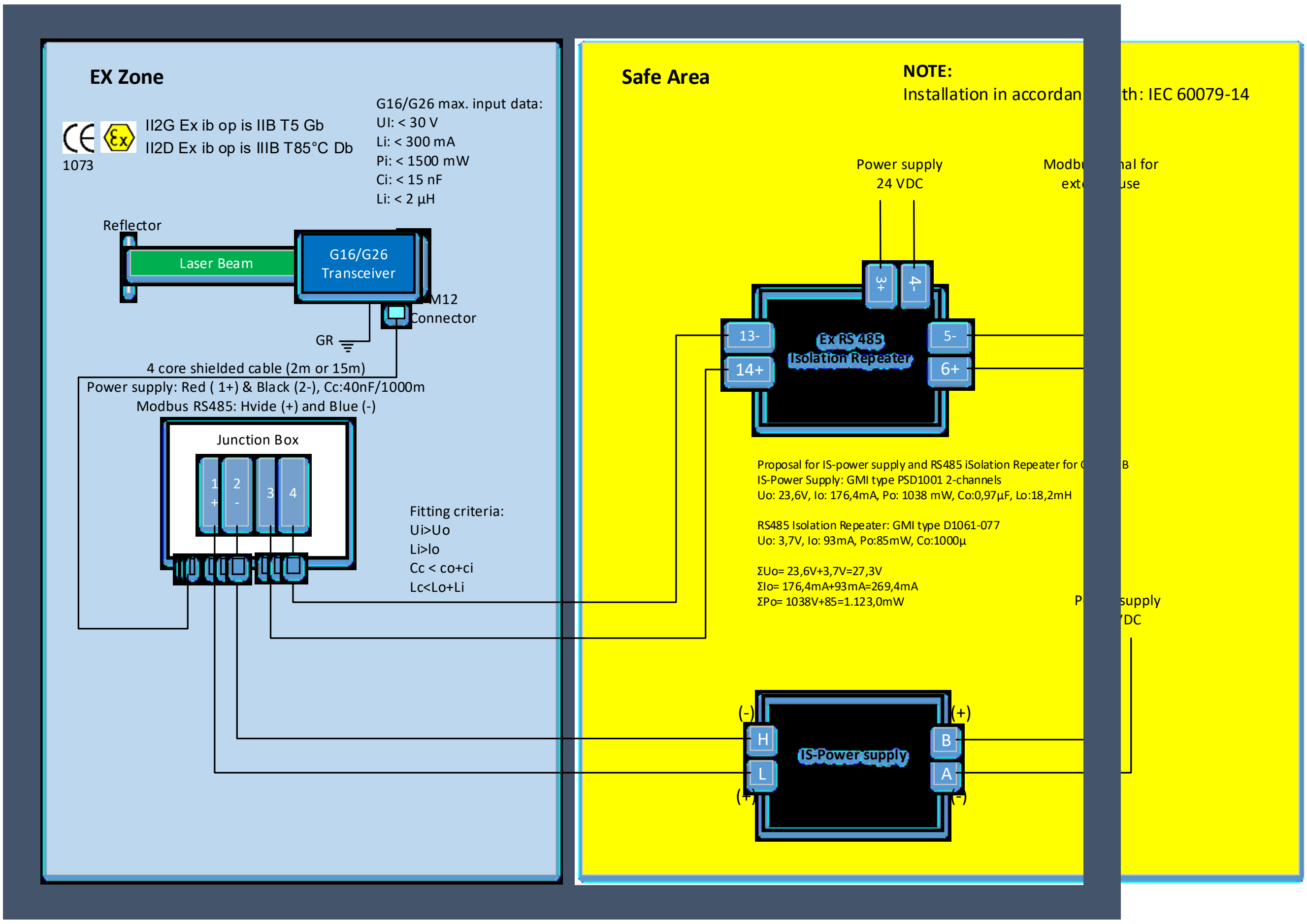
9. Production year of the device.

With support from Danish Technological Institute (DTI) design and technical issues were evaluated and a product road map established with about 25 focus items to be addressed, including:

1. Laser power, optical radiation and laser classification
2. Power consumption
3. Intrinsic power supply and evaluations
4. Component selection
5. Mechanical design
6. Encapsulation
7. Connections and interface
8. Sparke ignition
9. Temperature rating
10. PCB layout and requirements
11. Quality Assessment (QAR and PQAN)

For determination on laser power and laser classification Danish National Metrology Institute (DFM) has been a great support. Beside laser power measurements, they have also provided valuable input around particle measurement and scattering.
Especially the Ex protection work has taking much more time than expected because of required re-design of the electronic control board (PCB) taking into account the requirements to low power consumption. In connection with the Ex re-design a low power cortex processor type MKL17Z128VFM4 was selected.

The installation and connection between Ex Zone and Safe Area is illustrated in figure 11:



FIGUR 11. Ex zone and safe area connection

8. Development

The development-process and challenges, can as mentioned earlier be summarized to the following main elements:

a. Probe and sample system
b. Measuring System
c. Controller and user interface
d. Ex certification

The product requirements and the way forward was established based on input from the market and advisors.

Aalborg University, department of physics and nanotechnology has supported with laser optic and tests of the laser beam. From Danish Technological Institute we have been guided into the ATEX and IECEX protection requirements and from actually test of our standard Transceiver head the way forward with EX protection has been established. On the electronic (PCB) and mechanically side we have specified the requirements and new prototypes made.

The preliminary work around scattering and EX protection has taking more time than first expected. After the first round of scattering test, prototypes were designed and build for our first really performance tests and required samples for EX certification.

The re-designed low power laser control board, as required for Ex, was received end of December for software update and test. In connection with the Ex re-design a low power cortex processor type MKL17Z128VFM4 was selected.

For the Ex certification it is expected that all test units will be ready for DTI and CNEX end of January 2019.

For the Scattering probe, parts have been designed and are currently in production with our sub-suppliers. We expect to have all mechanical and optical parts ready for assembly end of January 2019.

Besides we have spent considerable more time on initial tests and evaluation than original planned for, it has also been a struggle with our sub-suppliers to deliver the required parts in time due to heavy workload.

9. Conclusion

The market for accurate measurement of Particulate Matter (PM) in wet-gas is growing and we have received positive response from the marine industry. The scrubber market is currently in a positive development driven by the 2020 global sulfur cap.

The International Maritime Organization has after years of uncertainty announced it will go ahead with a global sulfur cap of 0.5% on marine fuels starting from January 1, 2020. With the 2020 date confirmed by the IMO, we expect more focus on emissions from the shipping industry with requirements to measure actual emission in wet-gasses.

The first wet-gas PM emission monitoring system, based on opacity, is scheduled for installation November 2018 onboard a DFDS vessel.

The EX version, based on line of sight or point scattering, for wet-gasses or dust monitoring in hazards areas is not ready yet due to heavy delay from sub-suppliers and misinterpretation of the IECEx standards.
The Ex certification process is in progress and we expect early 2019 to have the product fully certified for zone 1 and 21 locations in a unique configuration for both wet and dry gasses/dust, which as far as we know no other companies can offer.

On a global scale, the market for wet-gasses, dust and oil-mist detection/monitoring in hazards area is huge and growing. From 2019 with the Ex certification process complete we will in addition to the marine market include certain markets segments of the land based industrial market.

Further the Ex solution will provide a broad range of opportunities for adapting other of our marine products to the industrial marked where our offices in USA and Singapore will be an integrated part of supporting the new land-based activities.

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