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Stand alone soot generation -
a new standard, adjustable in size and concentration

Stand alone Soot Generator - a new Standard, Adjustable in Size and Concentration

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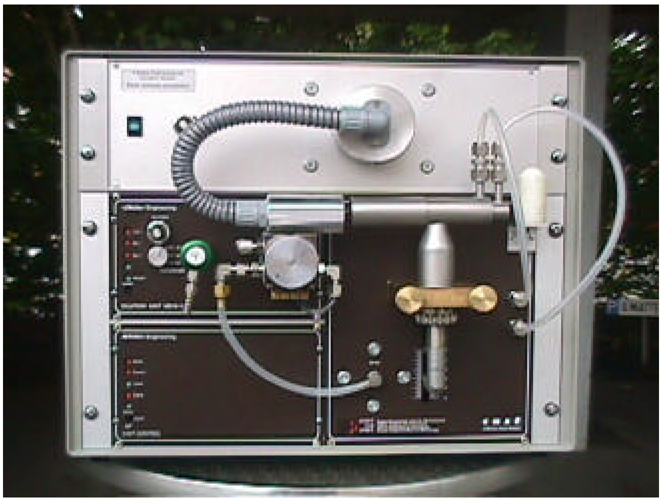
Datasheet of CAST Combustion Aerosol Standard



- **Real combustion particles for calibration purposes**
- **Adjustable mobility diameter range from 20 ... 200 nm**
- **Continuous setting of particle number concentration from 10^3 ... 10^6 #/cm^3**
- **High stability and reproducibility in size and concentration**

INTRODUCTION

Submicron particles emitted from combustion processes in high concentration worsen the air quality obviously. Due to their adverse health effects much efforts are done to measure and analyze these air pollutants in order to control emissions and reduce their assessment to the environment. Sensor and instruments for the measurement of submircon particles require test aerosols which are as similar as possible in size, chemical composition and morphology to the real combustion aerosols to be monitored. Generally the characteristics of carbonascons soot particles emitted from fossile combustions are sensitively depending on the combustion conditions, a reason for the difficulty to stabilize the formation and emission of soot particles in flames.

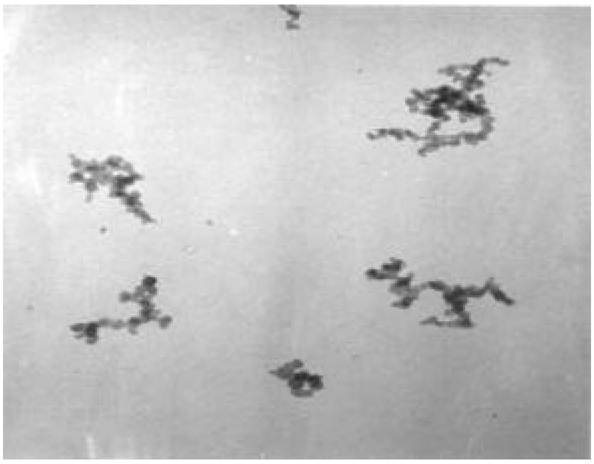


Fig. 1 TEM image from CAST soot particles

CAST, a generator of real combustion aerosols developed by Dr. Lianpeng Jing at the Swiss Federal Institute of Metrology applies in it's specifications to the severe requirements on accuracy and reproducibility for the use as a reference in calibration procedures. A special construction and gas control allows the generation of suspended particles in a wide size- and concentration range with a reproducibility of typically +/- 5 %. Their chemical composition and morphology is similar to those emitted from real combustion processes like diesel engines, wood- or coal combustions.

The generator is build up in a rugged 19" case for rack mounting or stand alone use. It's external components are the supply gas bottles for the C_3H_8 fuel gas, N_2, synthetic air, compressed air and a PC for control via RS 232-communication.

APPLICATIONS

CAST is an ideal tool to calibrate and adjust many sensors and instruments which are commonly used for fine particle measurement. Some of these are the condensation particle counter (CPC), the scanning mobility particle sizer (TSI SMPS), the diffusion charging (DC) sensor and epiphaniometer for active particle surface, the photoelectric aerosol sensor (PAS) for carbonaceous soot particles, the aethalometer for black carbon (BC) and personal samplers for coulometric carbon analysis.

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PRINCIPLE OF SOOT PARTICLE GENERATION

The principle of CAST presented here consists primarily in free-getting soot particles formed in a co-flow diffusion flame of hydrocarbon by preventing the further oxygenation in the flame over a certain flame height. In the next step the particle stream is mixed with quenching gas in order to prevent further combustion processes in the particle stream and to stabilize the soot particles.

Fig. 2 illustrates the construction of the flame unit. The gaseous fuel stream is concentrically surrounded by a stream of synthetic combustion air. In order to produce soot particles, the symmetrical diffusion flame is wrapped with a, tapering upward, circular truncated cone of steel. A position for the truncated cone is found whereby the smoke column withdraws from the upper opening of the combustion chamber despite the burning flame. In a certain flame height the combustion air is insufficient for further oxiditation of the generated soot particles. Leaving the combustion chamber by the upper opening, they are wrapped by exhaust gases which develop around the flame what prevents the particle stream from depositing at the device walls. In a pipe arranged right angled to the flame axis N_2 is supplied to the particle stream to quench further combustion processes and stabilize the soot particles. To dilute the particle stream, compressed air is supplied through the gap between the two concentrical pipes. This dilution inhibits condensation in the particle stream when it escapes from the flame unit of ambient air condition.

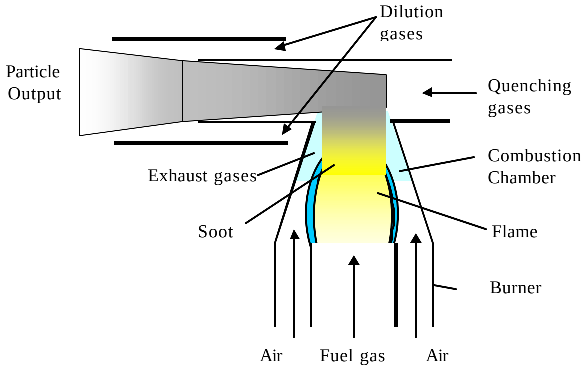

Fig. 2 burner unit

Soot particles with monomodal size distribution are generated in the flame unit and their mean diameter can be influenced by the flows of the different input gases. The variation of the mean particle size is mainly done by tuning the dilution of the C_3H_8 fuel gas with admixed N_2 and variation of the combustion air flow. A mean mobility diameter range from 20 to 200 nm is adjustable by variation of these flows.

CAST generates soot particles with high stability and reproducibility in size and number concentration. These excellent characteristics are achieved by the following features in the construction and gas control of the generator.

- The combustion chamber is shielded from the environment, defined gases are used for the flame and a dilution is realized which suppresses influences from the environment conditions
- The laminar concentrical flows of the gases around the flame generate a sheath around the particle stream which prevents deposition of soot on the inner walls of the flame unit.

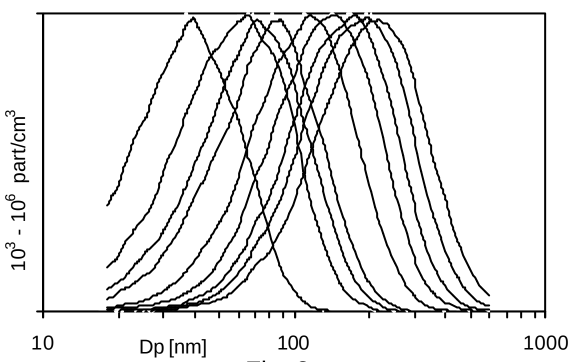

Fig. 3

Shapes of monomodal SMPS size distributions

BLOCK DIAGRAM

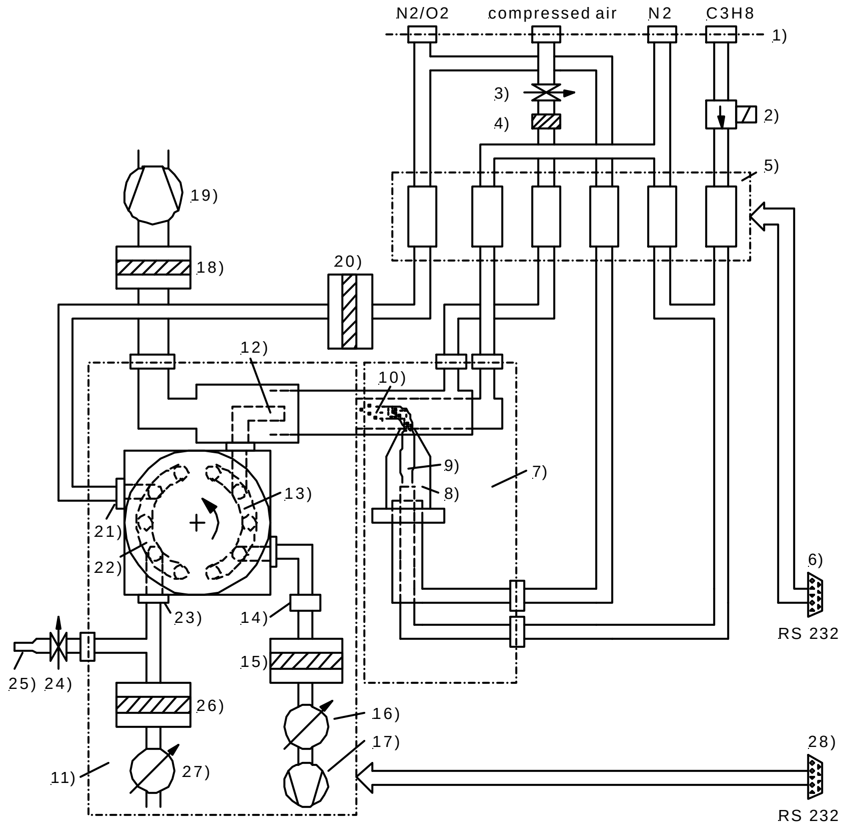

Fig. 4 functional block diagram

Legend

1) coded plug in gas connectors
2) security valve for fuel
3) reduction valve for pressure air
4) oil filter
5) mass flow controllers
6) RS232 for mass flow controllers to PC COM1
7) burner unit
8) combustion chamber
9) co-flow diffusion flame
10) test aerosol output to dilution unit
11) adjustable dilution unit
12) prediluted test aerosol input with flame detection
13) undiluted gas channel
14) connection for alternative filter analysis
15) particle filter for prediluted test aerosol
16) flow sensor for undiluted gas
17) pump for undiluted gas
18) particle filter for excess exhaust
19) pump for excess exhaust
20) particle filter for dilution air
21) dilution gas input
22) diluted gas channel
23) diluted test aerosol output
24) fine adjustment valve for zero pressure adjust
25) test aerosol output to sensor(s) under test
26) particle filter for excess test aerosol
27) flow sensor for excess test aerosol
28) RS232 for dilution- and security control to PC COM2

PRINCIBLE OF OPERATION

The principle of operation is explained by the block diagram Fig. 4.

High particle concentrations in the range of 10^7 - 10^8 part./cm^3 escape from the test aerosol output 10) of the burner unit 7) whose gas flows are adjusted in high stability precision mass flow controllers 5). An additional controlled dilution is therefore necessary to reduce the concentrations down to ranges of appr. 10^3 to 10^6 part./cm^3 as they are required for most sensor(s) under test. The dilution unit 11) is a modified version of the standard gas and aerosol dilution unit Matter Engineering type MD19-1i.

The gas bottles and compressed air are connected to the generator via coded plug-in pneumatic connectors which automatically close on both sides, when they are disconnected. A normally closed security valve 2) behind the C_3H_8 fuel gas input is only opened when a temperature sensor near the diluter input 12) recognizes the heat of the flame.

Control and settings of the generator are done by PC in a LabVIEW-application via two serial RS communications. Connection 6) is used to control the mass flow controllers and connection 28) for the setting or reading of the dilution factor in the unit 11) and for additional controls.

The software offers several discrete particle mean diameters from 20 to 200 nm. The particle concentration is either numerically selected in the software or adjusted on a 10-turn potentiometer of the dilution unit while the corresponding particle concentration is displayed on the PC. A number of system controls provide a safe and reliable operation with detection of errors or unspecified conditions to minimize the risk of malfunctioning.

Two analog inputs allow to compare sensor readings to the generated soot concentrations in calibration routines.

PRELIMINARY SHORT SPECIFICATIONS

Aerosol	Soot particles generated in C_3H_8-diffusion flame (propane)
EC/OC-concentration	75 % (30 nm), 97 % (110 nm), 99 % (200 nm)
size distribution	monomodal, bimodal
mean diameter	several mean mobility diameters from 20 to 200 nm on choice
concentration	0 ... appr. 3 x 10^6 part./cm^3 adjusted - manually on 10-turn potentiometer - numerically on PC
accuracy	10 % for number concentration
	5 % of selected mean size +/- 3 nm
reproducibility	± 5 %
aerosol flow	0,2 ... 5 l/min = flow sucked by sensor(s) under test
Gas-supply	C_3H_8 (propane) appr. 0.1 l/min, purity 99,95 %
	$0_2/N_2$ (21/79%), synthetic air, appr. 7 l/min, mixing accuracy +/- 10 %, $C0_2$ < 10 ppm, H_2O < 10 ppm
	N_2 appr. 10 l/min, purity 99,999 %
	compressed air appr. 25 l/min
Operation and control	by LabVIEW application on separate PC
communication	via 2 RS 232 links
analog inputs	2 inputs +/- 10 V DC, 12 bit resolution for sensor(s) under test
Case	9HE-19"-case, dimension appr. 510x400x500 mm (WxHxD)
weight	appr. 40 kg
Supply	90 - 260 V AC, max. 140 VA
Accessory	separate pump with particle filter for excess exhaust

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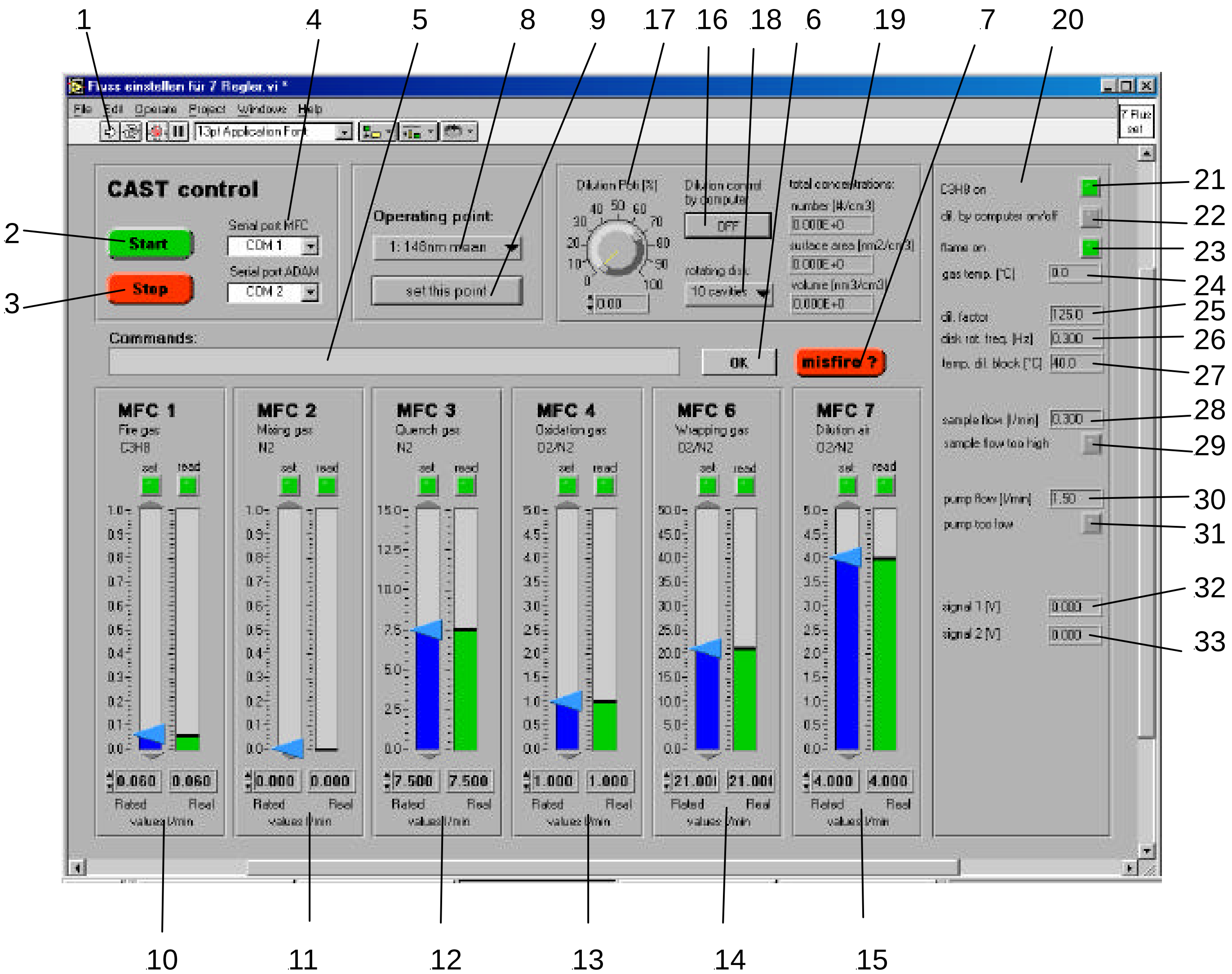
CAST Software-Description



Description of Operation Elements and Readings

1. Start of LabView-vi
2. Start button for test aerosol generation
3. Stop button appears after pressing ”Start“ (2). “Stop“ terminates the program, closes the fuel gas input and flushes the tubes to remove all combustible gases from the system.
4. COM-port-assignment, has to be configurated before ”Start“ (1).of LabView.
5. Display of interactive user commands for manipulations on the CAST during the start procedure (ignition of the flame).
6. Press “OK” when the manipulation according to the command on (5) is done.

7. Program step can be stopped and repeated in case of incorrect manipulation.
8. Selection of discrete mobility particle sizes between 30 and 200 nm or manual programming of mass flow controller flows.
9. Pressing this button sets the mass flow controllers to the flows corresponding to the selected (8) particle size
10. Reading for the propane fuel gas flow. The left bar displays the set value corresponding to the selected particle size (8 & 9). The real mass flow is indicated on the right bar. Both values are additionally displayed as digital numbers below the bars. Two LED's "set" and "read" are green or red when the serial communication to the mass flow controllers is OK or incorrect.
11. mass flow controller for the N_2 mixing gas.
12. mass flow controller for the N_2 quenching gas.
13. mass flow controller for the N_2/O_2 combustion air
14. mass flow controller for the N_2/O_2 or compressed primary dilution air
15. mass flow controller for the N_2/O_2 secondary dilution air to the adjustable dilution unit
16. Manual or remote setting (by PC) of the dilution ratio on the adjustable dilution unit
17. Remote Setting of dilution ratio on the adjustable dilution unit. 100 % corresponds to end position of the 10-turn potentiometer in manual setting
18. Specification of the rotating disk (2 or 10 cavities) on the adjustable dilution unit for calculating the dilution ratio.
19. Display of the total particle number concentration depending on the selected particle size and dilution ratio.
20. Window with several status signals and measured parameters in CAST.
21. Status signal, green when the security valve between the propane gas bottle and the mass flow controller is open.
22. Status signal, green for remote setting of the dilution ratio by PC.
23. Status signal, green when the flame in the burner is lighted.
24. Temperature of the test aerosol entering from the burner to the adjustable dilution unit.
25. Dilution factor for secondary dilution between input and output of the adjustable dilution unit.
26. Rotation frequency of the rotating cavity disk on the adjustable dilution unit.
27. Temperature on heated dilution block and of secondary dilution air. (Setting on rotating switch to 40, 80 or 120 °C).
28. Mass flow sampled from the sensors under test connected to the diluted test aerosol output.
29. Status signal when the sample flow (28) is too high (> 4l/min).
30. Sample mass flow of prediluted test aerosol from the burner in the undiluted gas channel of the adjusted dilution unit.

31. Status signal, red when sample mass flow is to low < 0.8 l/min, due to enhanced pressure drop over the particle filter in the indiluted gas channel. Indication for replacing the particle filter.

32. and 33. Analog signals of optional sensors connected to the analog inputs.