Producing CCI Calibrated Defects With Laser Technology and Gas Flow Dynamics

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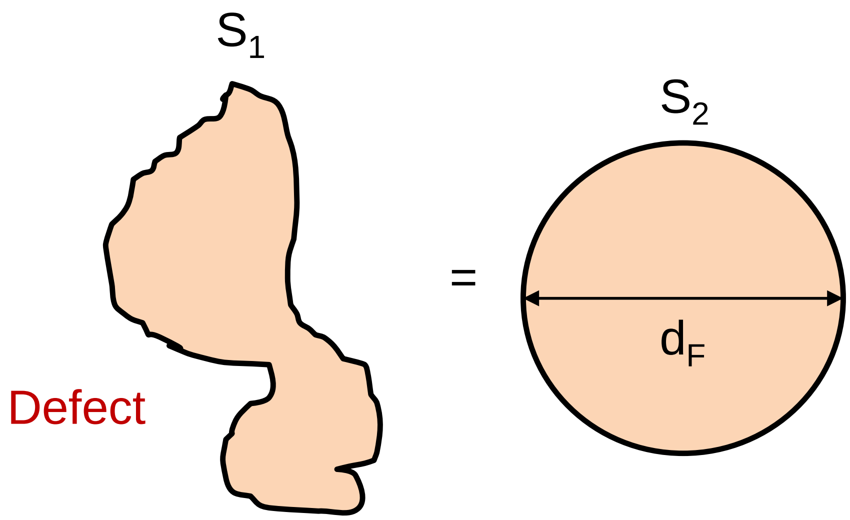
Major approaches for creating a calibrated leak

- Manufacturing with in-process calibration by laser drilling (non-destructive)
- Cross calibrating the leak with different test methods (both non-destructive and destructive)
- Manufacturing with statistical (sampling) calibration (mostly destructive)

Glossary

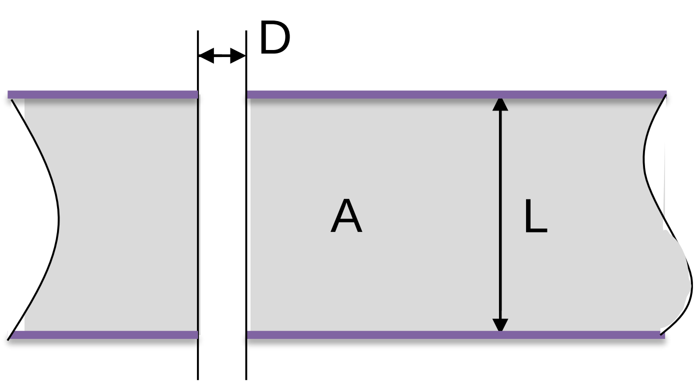
A	Area [m^2]
α	Speed of sound [m/s] or radius of laminar flow meter [m]
FC	Flow Coefficient = $D^3\Delta P/(\mu Q)$ a form of discharge coefficient for laminar flow meters [-]
g	Gravitational acceleration, ~9.8 [m/s^2]
M	Molar mass [kg/kgmole]
M	Mach number [-]
P	Absolute Pressure [kPa]
Q	Volume flow [m^3/s]
R_U	Universal Gas Constant, 8.314472 [m^2 kg/(s^2 K kgmole)]
Re	Reynolds Number, $\rho d\bar{u}/\mu$ [-]
V	Volume [m^3]
μ	Dynamic Viscosity [kg/(m s)]
V	Kinematic viscosity, μ/ρ [mm^2/s = cSt]
ρ	Density [kg/m^3]

Flow Effective Diameter



$$S_1 = S_2 = \pi \frac{(d_F)^2}{4}$$

Aspect Ratio



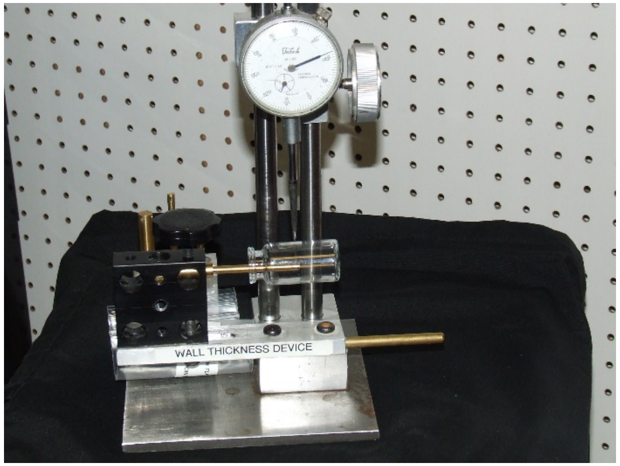
L = (mm) length of a channel
D = (mm) diameter of a channel
A = L/D (n*10, n*100, n*1000)

Prequalification of containers: syringes, ampoules and vials for laser drilling

- Measurement of the wall thickness deviation
- Selecting the methods of preprocessing (mechanical, laser beam)
- Optimizing the laser parameters for material composition
- Selecting the metrology methods for different contents of the containers (developing the repeatability, nondestructive and destructive methods)
- Selecting the correct methods and ways of handling: mechanical fixtures for drilling, marking, testing, storing, shipping

Measurement of the wall thickness deviation (Fig.1)

- The thickness of the material (glass, plastic) varies in different parts of the given container such as ampoule, syringe and bottle.
- Although this thickness is defined on the drawings of the manufacture of the given containers, it may vary by 50%.
- The diameter of the microhole is effected by this thickness variation.
- Therefore Lenox Laser performs its own study of the thickness in the areas selected for a drilling by customer. Sometimes these methods are destructive.



Selecting the metrology methods for different contents of the containers

- The containers supplied for the calibrated leak manufacturing may be empty or filled with liquid. The containers also may be open to the ambient atmosphere or sealed, having the internal pressure above or lower then ambient.
- In each particular case one or more hole calibration methods may be used.

The methods include:

1. Mass flow, volumetric methods (volume vrc. time).
   Standard: leak standard.

2. Optical microscope method (geometrical size and shape).
   Standard: optical standard.

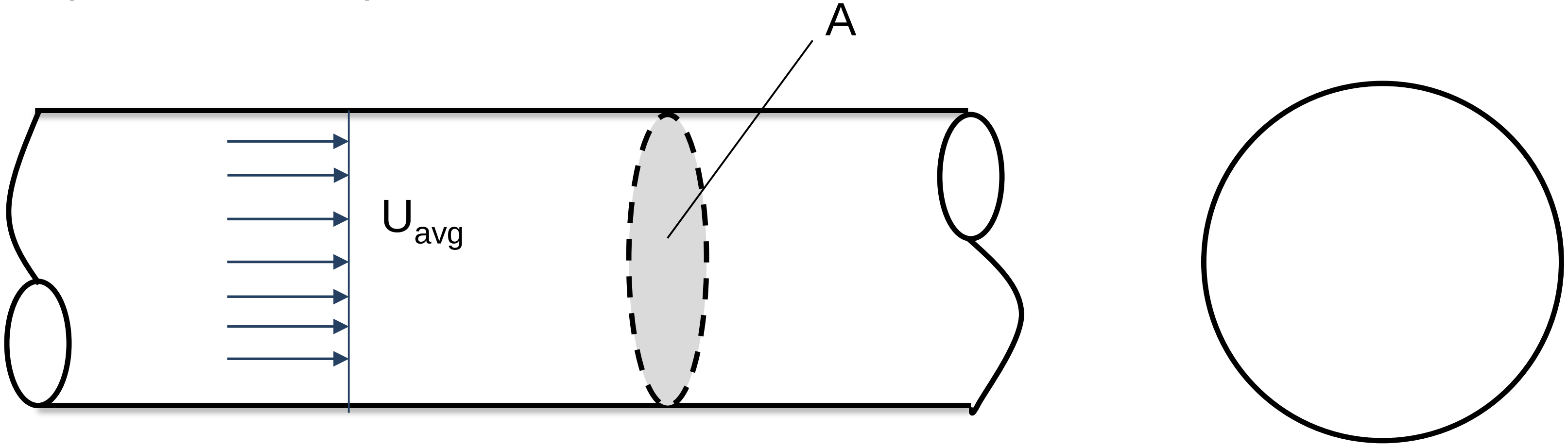
3. SEM method (geometrical size and shape on nano scale). Standard: nano sphere.

Volumetric Flow (Simplified)

$$Q = U_{avg} A$$

U_{avg} = Average Fluid Velocity
A = Cross Sectional Area

Pipe Flow Example



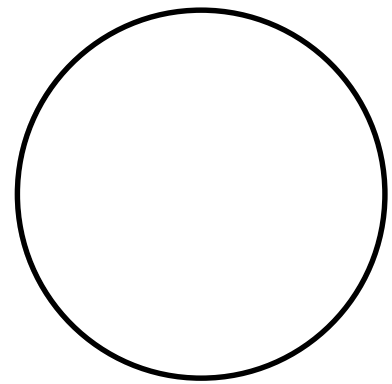
SI unit: m^3/s, m^3/min, m^3/hr
Other units: Lpm (liters/min), gal/min, cm^3/min (ccm), ft^3/hr (acfh) …

Mass Flow (Simplified)

$$\dot{m} = \rho(U_{avg}A) = \rho Q$$

U_{avg} = Average Fluid Velocity
A = Cross Sectional Area
ρ = Fluid Density

Pipe Flow Example



SI unit for mass flow: kg/s, kg/min, kg/hr, g/s, g/min, g/hr
Other units: lb/s. lb/min, lb/hr

Fluid Density

- Most flowmeters measure Q (or U_{avg})
- Mass flow is usually the desired measurand
- Density is needed to convert to mass flow
  - Densimeter – Liquid and high pressure gas
  - Equation of State: $\rho = \rho(T, P, x_k)$

T = Temperature Measurements
P = Pressure Measurements
x_k = Composition Measurements

Reynolds Number

Definition:

The ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities, in which is known as a boundary layer in the case of a bounding surface such as the interior of a channel

$$\mathrm{Re} = \frac{\rho D \bar{u}}{\mu} = \frac{4Q\rho}{\pi D \mu} = \frac{inertial}{viscous}$$

Some equivalent Reynold's numbers definitions:

$$\mathrm{Re}_D = \frac{\rho U_{avg} D}{\mu}$$

Based on average velocity, density, and absolute viscosity

$$\mathrm{Re}_D = \frac{U_{avg} D}{v}$$

Based on average velocity and kinematic viscosity

$$\mathrm{Re}_D = \frac{4m}{\pi \mu D}$$

Based on mass flow

$$\mathrm{Re}_D = \frac{4Q}{\pi v D}$$

Based on volumetric flow

Flow Through Small Calibrated Orifices

$$Flow = C * P_{in} * \sqrt{\frac{29}{M.W.Gas}} * Factor\#3 * \sqrt{\frac{528}{Temp^{\circ}R}} * d_1^2$$

$$d_1 = \sqrt{\frac{Flow}{C * P_{in} * \sqrt{\frac{29}{M.W.Gas}} * Factor\#3 * \sqrt{\frac{528}{Temp^{\circ}R}}}}$$

Flow = cubic centimeters per minute [cm^3/min]
$\Delta P = P_{in} - P_{out}$ in designated pressure units
d_1 = flow diameter in micrometers [µm]
C = constant depending on pressure units

M.W. Gas = Molecular of gas mixture
Factor #3 = Factor used to calculate gas flow when $\Delta P/P_{in}$ is less than 0.5
C = constant depending on pressure units

Flow Effective Diameter to Air Flow Reference Table

Flow Effective Diameter [µm]	T = 21° C, P_{in} = 29.7 PSIA, P_{out} = 14.7 PSIA	T = 21° C, P_{in} = 14.7 PSIA, P_{out} = 0.01 Torr
5	0.437	0.216
10	1.748	0.865
20	6.991	3.46
50	43.695	21.62
100	174.8	86.5

P_{in} = Inlet Pressure
P_{out} = Outlet Pressure

Flow Through Small Calibrated Orifices (cont.)

Liquid flow can be predicted the same as gas flow through calibrated orifices. However, liquid is not compressible and different formula are required for calculations

$$Flow = .0001423 * \sqrt{\frac{\Delta P}{\rho}} * d_2^2$$

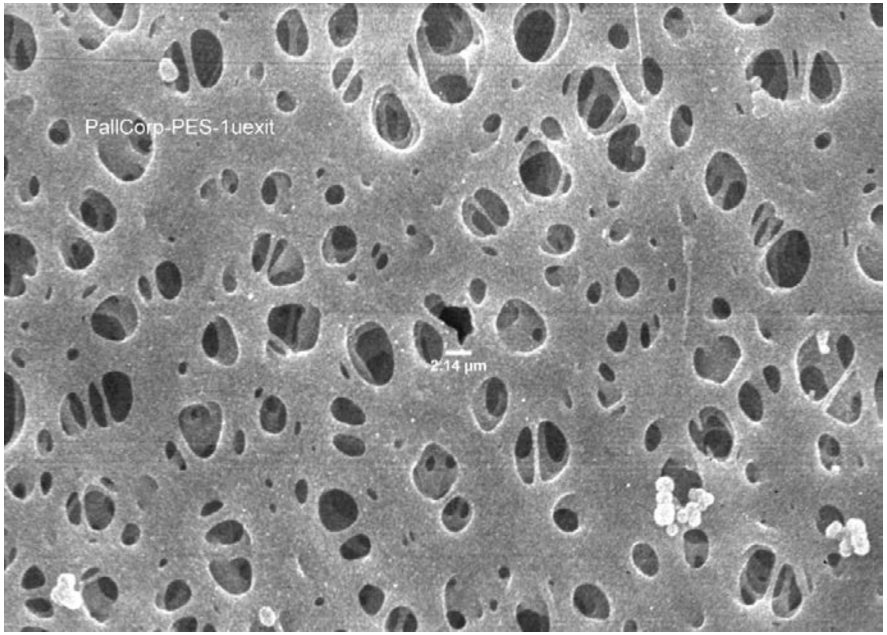
$$d_2 = \sqrt{\frac{Flow}{.0001423 * \sqrt{\frac{\Delta P}{\rho}}}}$$

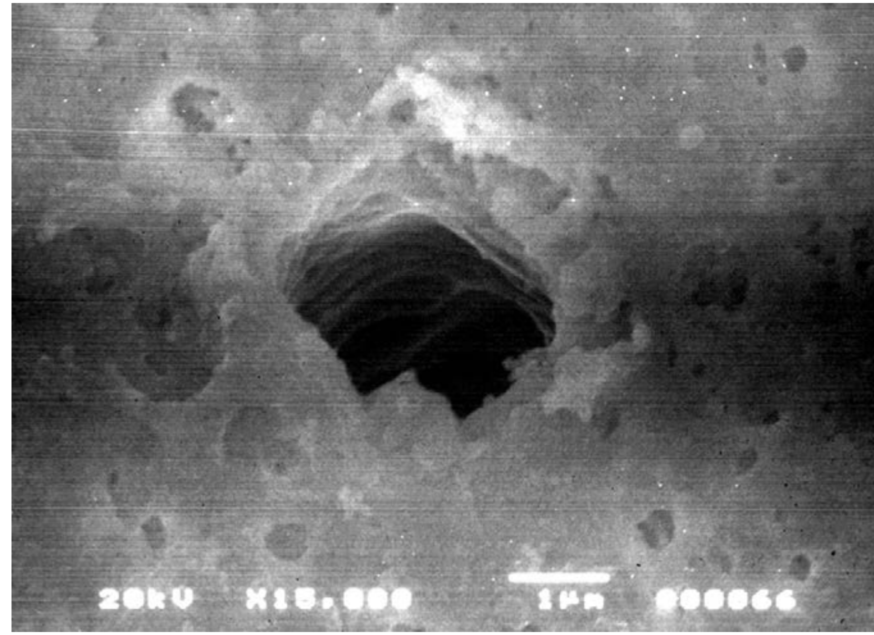
Flow = cubic centimeters per minute [cm³/min]
d_2 = flow diameter in micrometers [µm]
$\Delta P = P_{in} - P_{out}$ in pounds per inch² [lbs/in²]
ρ = density relative to water

Definition:

Process of removing material from a solid surface by irradiating it with a very short, high energy laser pulse. During this process the material is converted to a plasma from a solid state directly. The absorbed laser energy is not converted to a heat.

Laser pulses have to be of the order of hundred(s) of femtoseconds (fs) 10^{-16} [s] to a few picoseconds (ps) 10^{-12} [s] long.


PallCorp-PES-1uexit
2.14 µm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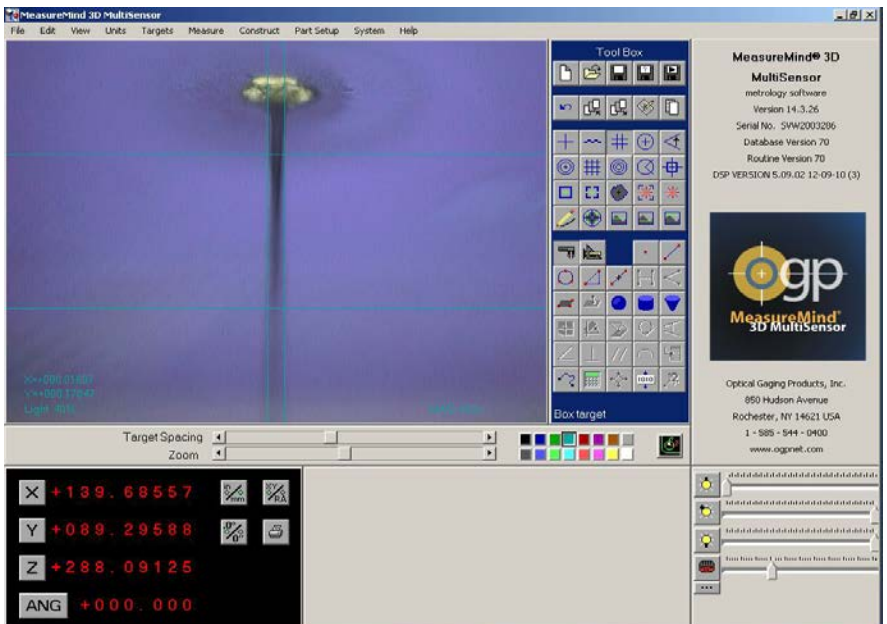
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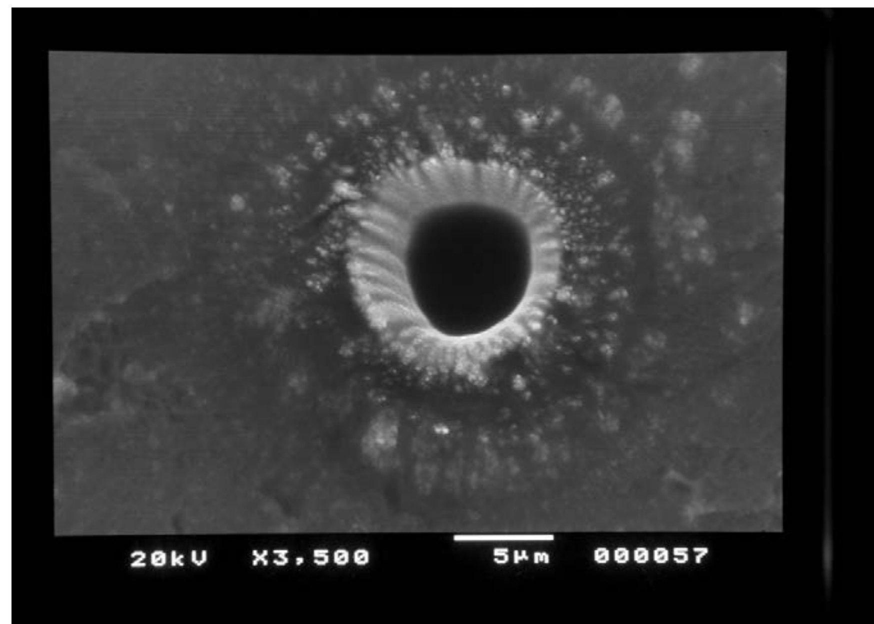
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Lenox LASER

Leader in creating calibrated Micro-Leaks