Measurement of Lubricant Aeration:

A Theoretical and Experimental Approach

By Thierry Delvigne

DSi Belgium

CEO

www.deltabeam.net

September 19, 2024

ABOUT DSI

REAL-TIME MEASUREMENT SOLUTIONS FOR MODERN POWERTRAINS

- Established in 2000 – Based in Belgium
- **R&D partner** for the development of lubricants in the industry (automotive, aeronautics...)
- **World leader in radiotracer techniques** to monitor lubricant properties
- **Our Products**: on-site measurement services, sales and rent of equipment, engine & lubricant testing, development of test rigs and ancillary systems
- Test facility in Belgium (4 engine test benches & 2 friction test rigs)

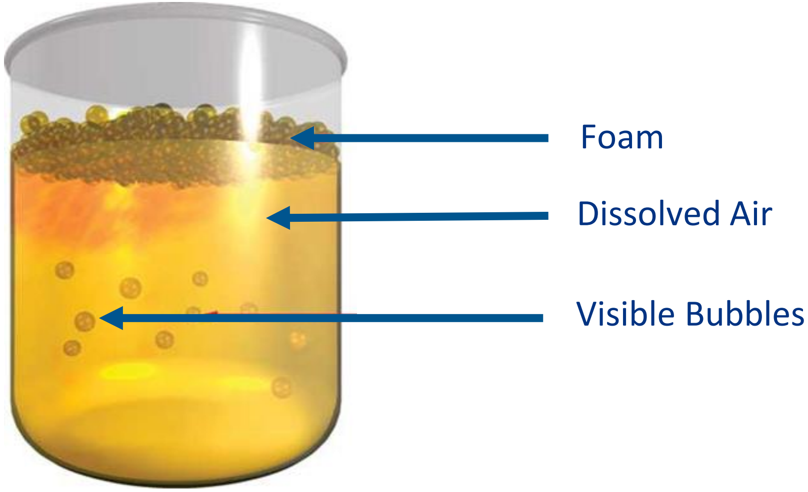
GAS CONTENT ISSUES

Air-in-oil may be in an **entrained (bubbles) or dissolved state (not visible)**

Aeration can directly affect fluid parameters: density, bulk modulus, compressibility, etc.

It can cause significant performance and reliability problems:

- Loss of lubricity
- Cavitation & Wear
- Malfunction of hydraulic systems
- Higher oil temperature
- Wasted horsepower
- Noisy operation
- Engine failure



IMPACT OF PRESSURE ON DISSOLVED / NON-DISSOLVED FRACTIONS

Henry-Dalton's law

When pressure is increased by 1 bar, ~ 9% additional air is dissolved in oil (in volume)

→ 9% air already dissolved at atm. pressure (1 bar absolute)

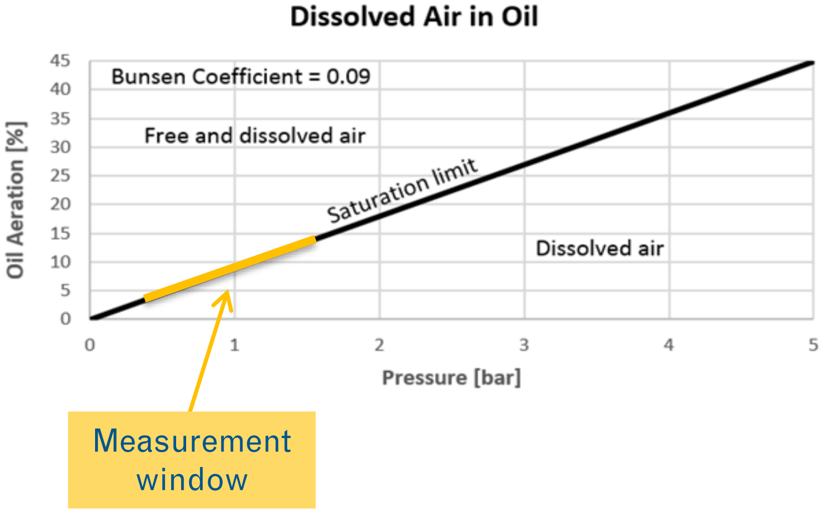
→ at 5 bars (6 bars absolute) → up to 54 % dissolved air in oil!

Dissolved air fraction is (almost) not measurable!

→ Pressure must be reduced to perform air content measurement

→ I.e. when oil is sampled from a gallery (pressurised line), a pressure drop is required before performing the measurement

Henry-Dalton's Law :



IMPACT OF PRESSURE ON BUBBLE SIZE

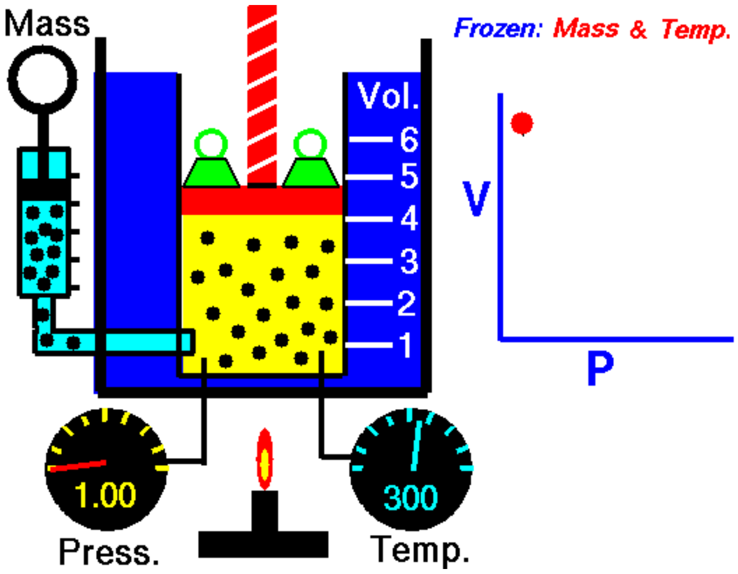
Boyle's law

When pressure is increased the size of air bubbles decreases proportionally: **P x V = Constant**

→ Size of bubbles depends on local pressure in the measuring device!

Typical Aeration Rates

- I.C. Engines: 1-10 % at operating temperature of 90°C
- e-motors: 3-15% (motor + transmission)
- Large industrial transmissions: 1-5%
- Dry sump engines: 30-70% (efficient air/oil separator required)



HOW TO MEASURE AIR CONTENT IN A LIQUID (1/3) ?

Standard methodologies with test tubes:

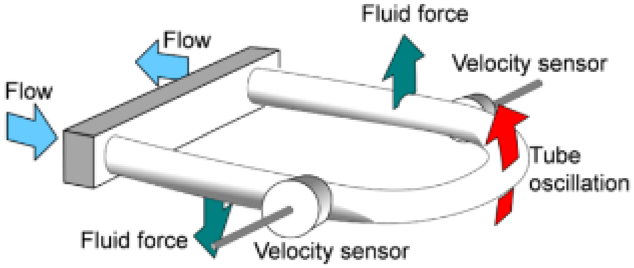
- ✓ Off-line measurement
- ✓ A sample of oil is taken
- ✓ Oil level measurement after de-aeration
- ✓ About 15 min. waiting time per oil sample

- ✓ Simple and low cost
- ✓ Requires much time and manpower
- ✓ Off-line
- ✓ Poor accuracy (temperature also has an impact on oil volume)

HOW TO MEASURE AIR CONTENT IN A LIQUID (2/3)?

Coriolis Probe

- ✓ Mass flow Measurement
- ✓ Easy calibration
- ✓ Convenient (and accurate) only when air/oil mixture is homogeneous
- ✓ Loss of signal when 2 phases appear
- ✓ Limited to max. 6 - 10% air content (homogeneous mixture)



In-line Impedance Measurement

- ✓ Quite simple to use
- ✓ Moderate cost but…
- ✓ Only for very low conductivity liquids
- ✓ Limited accuracy – how to get an absolute calibration?
- ✓ Limited flow rate → bypass configuration required

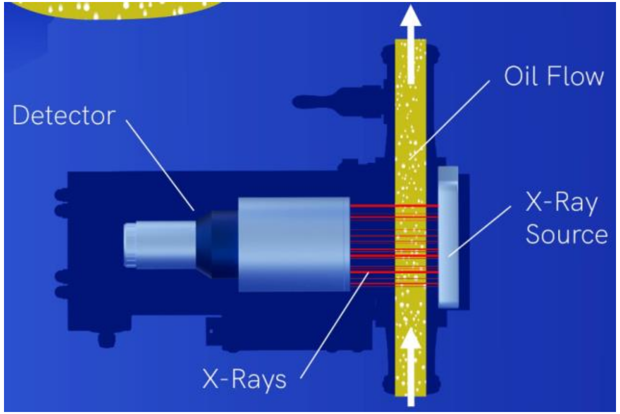
HOW TO MEASURE AIR CONTENT IN A LIQUID (3/3)?

X-Ray transmission

- ✓ In-line Density measurement
- ✓ Based on attenuation of low energy X-Rays

Oil density depends on 2 parameters:

- ✓ Oil temperature (automatic compensation)
- ✓ Air content (non-dissolved fraction only)
- ✓ Real-time results
- ✓ Measuring range 0-100%
- ✓ Self-calibration 0% - 100%
- ✓ X-Ray source must be replaced every 3 years



$$I = I_o e^{-\mu \rho x}$$

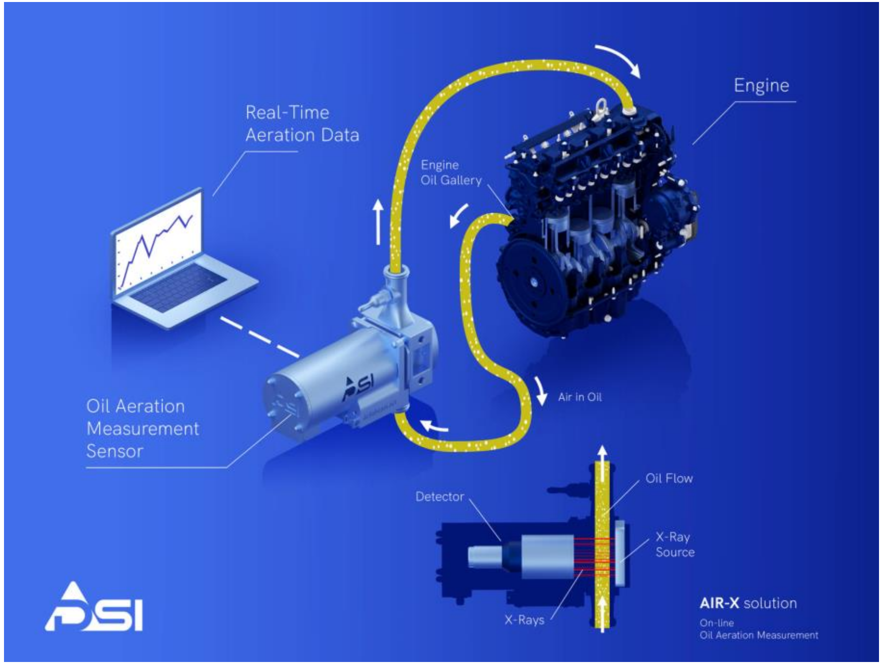
where

- I_o = incident intensity
- I = transmitted intensity
- μ = **mass** absorption coefficient (cm^2/gm)
- ρ = density (gm/cm^3)
- x = path length (cm)

SET-UP FOR AIR CONTENT MEASUREMENT WITH X-RAYS

Continuous measurement:

- ✓ Oil is sampled from a sump (tank) or from a gallery
- ✓ Oil is circulated into the X-Ray chamber to measure air content at atmospheric Pressure
- ✓ Oil is returned to the tank/sump after measurement

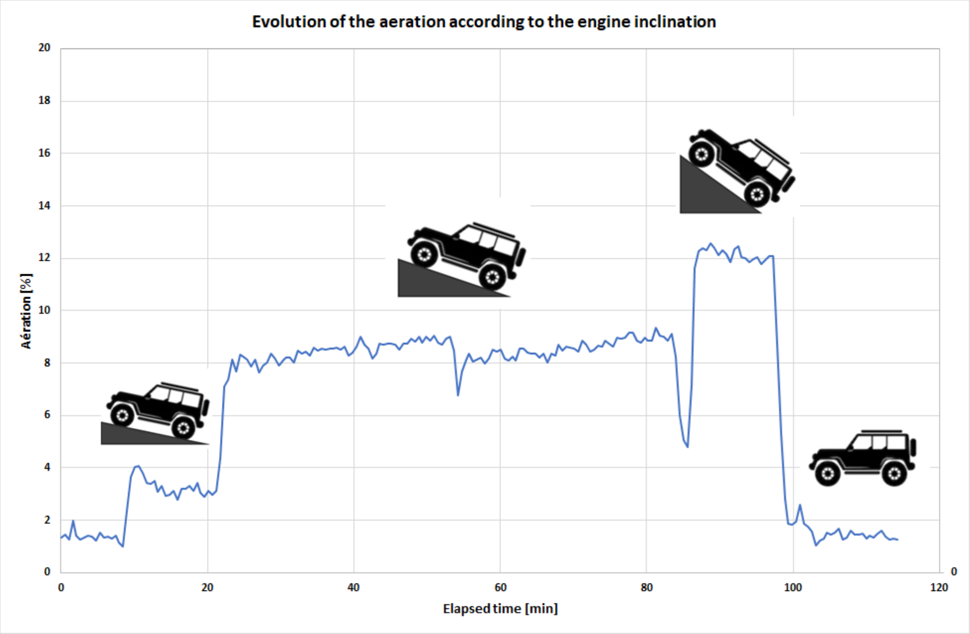


SUPER COMPACT X-RAY PROBE FOR OIL AERATION MEASUREMENT

AIR-X ON OFF-ROAD MINING VEHICLES

USE ON VEHICLES AND TILT TEST BENCH

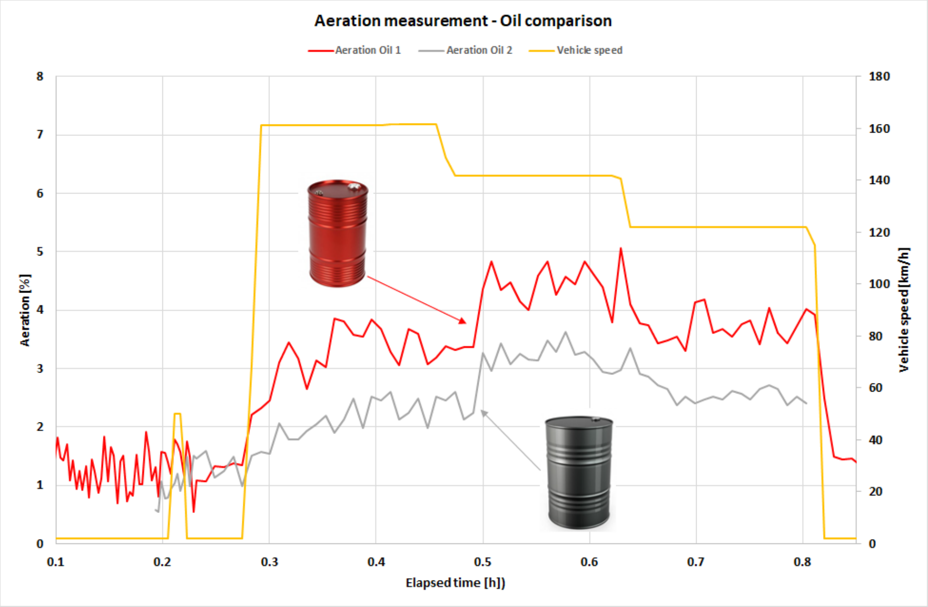
To determine the critical inclination when air is sucked in by the oil pump



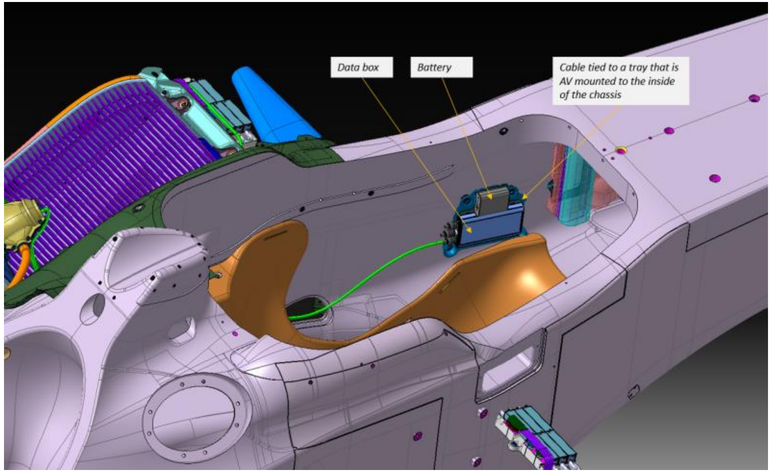
BENCHMARK OF LUBRICANTS

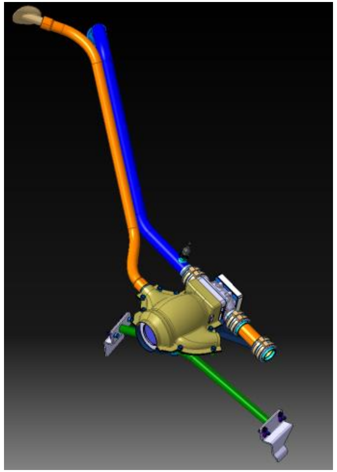
Measurement performed on e-powertrains (motor + transmission)

- ✓ Road cycles or simulation on test rigs
- ✓ Aeration rates are compared for different lubricant formulations
- ✓ Typically 1-hour test per lube
- ✓ Real-time results
- ✓ Tests can be repeated after oil aging



AIR-X APPLICATIONS

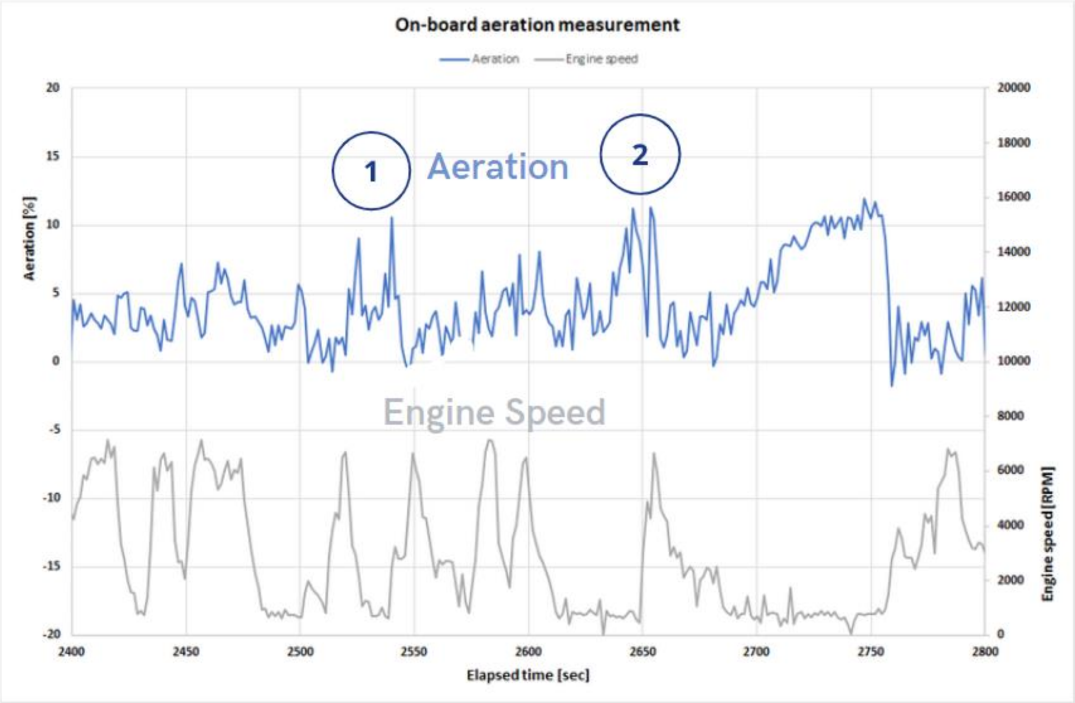


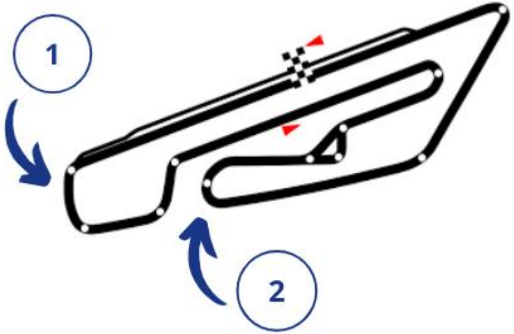


RACING CAR

Ultra compact and lightweight Air-X system for integration in a F1 racing car, with integrated electronics and data acquisition system

AERATION MEASUREMENT ON TRACK





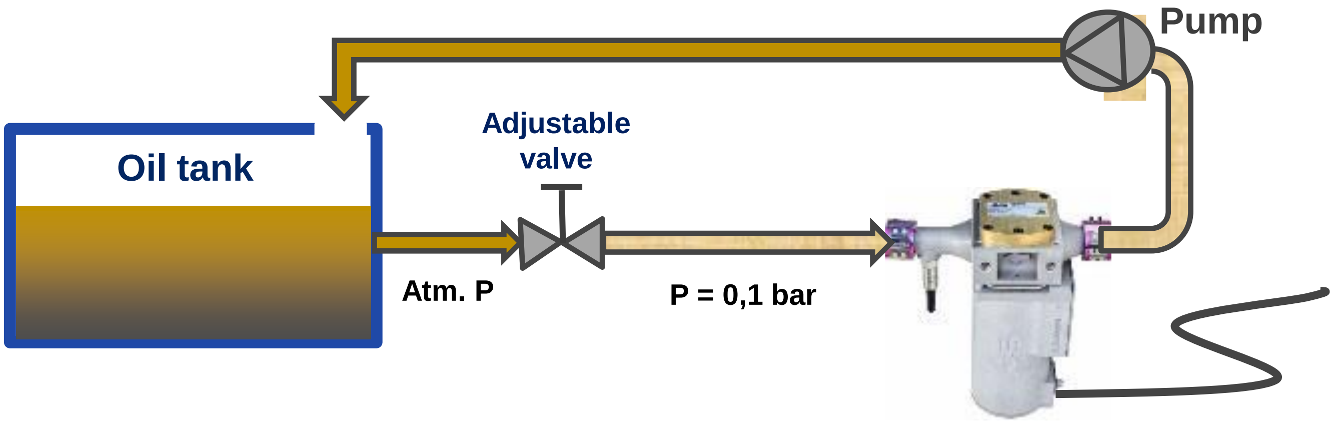
HOW TO MEASURE THE DISSOLVED AIR FRACTION?

Operating Principle:

Oil is circulated in the probe - A pump is installed downstream

A valve limits the flow → Pressure drops to ~ 0,1 bar in the measuring chamber

→ Dissolved air comes out and the amount is measured by the sensor

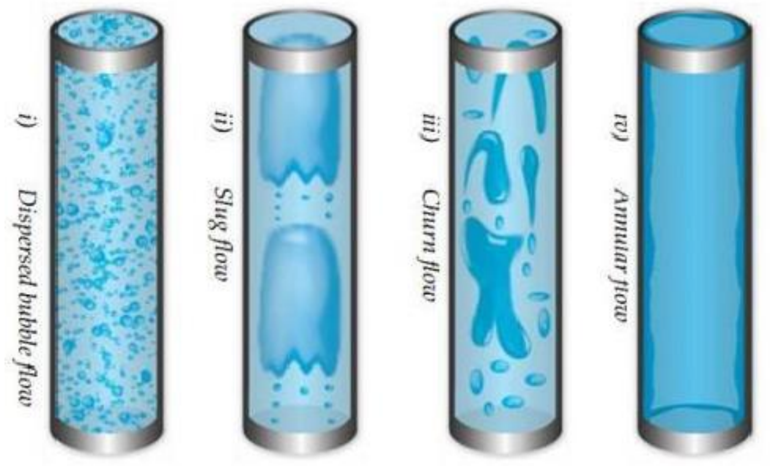


HOMOGENOUS & HETEROGENOUS AIR-OIL MIXTURES

When air is dispersed homogenously local pressure remains stable in the piping (and in the measuring probe)

When air content is **higher than 10-15%** air-oil mixture becomes non-homogeneous, which makes measurement more difficult:

- Turbulent flow: air « packets » are continuously compressed and depressed by oil packets → size of bubbles constantly changes due to changes of local pressure (P x V = Cst)
- The ratio between dissolved / non dissolved fractions also changes locally
- Oil flows preferentially along piping walls and bubbles preferentially at the centre
- A vertical positioning of the measuring chamber is recommended to avoid 2 layers oil-air due to gravity



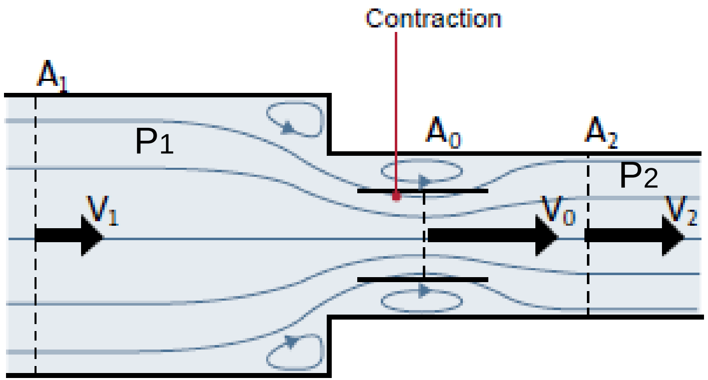
IMPACT OF PIPING GEOMETRY

Changes of sections must be avoided in the vicinity of the measuring device:

A change of section means:

- Change of fluid speed (V)
- Change of local pressure (impact on the size of bubbles)
- Creation of “dead zones” where oil/air can stagnate

Impact of geometry is even more important when sections are different and when the ratio air/oil increases (turbulent flow)



CONTROLLED AIR-IN-OIL GENERATOR

FLUID CONDITIONER TO SIMULATE AERATION PRODUCED BY INDUSTRIAL EQUIPMENT

Production of fine or “gross” aeration:

- “**FINE bubbles**” → 15 to 25% aeration rates
- “**LARGE” bubbles”** → up to 80% aeration rates

Adjustable **flow**, **pressure**, **temperature** and **aeration** level

Applications:

- Development of oil de-aeration systems
- Test of transmissions and hydraulic systems
- Test of engine subsystems (valve train...)
- Test of oil filtering systems
- Simulation of dry sump racing engines in terms of oil flow, pressure and aeration levels

THANK YOU FOR YOUR ATTENTION!

COME AND MEET US FOR A DEMO AT STAND 553