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MENAPS 2022

MIDDLE EAST AND NORTH AFRICA PERFORATING SYMPOSIUM

Comparative Evaluation of Alternative Technologies Used to Determine Perforated Casing Entry Holes

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The Opportunity

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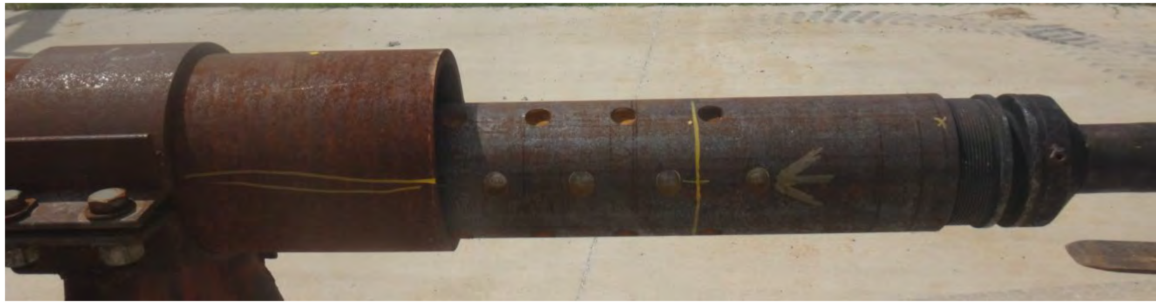
The Gun Systems

- In 2017 a GOM operator wished to trial Big Hole & Deep Penetrating Charges in the same gun system, aka a salt & pepper system.
- A survivability test in fluid was required as the system had never been run before. The gun was not centralized

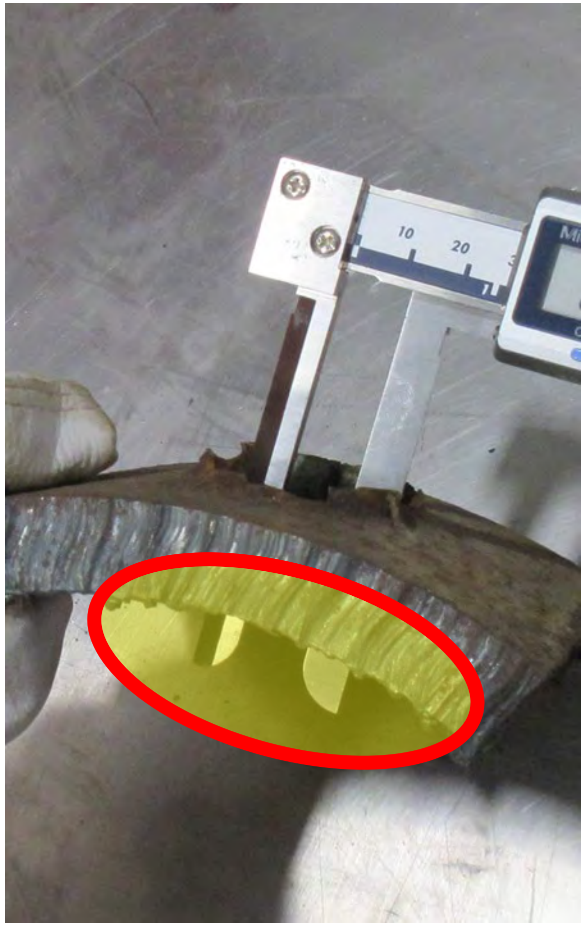
The Casing

- A representative 9-7/8” 62.8 # C110 casing was used to determine actual hole sizes
- As well as the traditional caliper measurement, it allowed the use of new technologies to determine the Area Open to Flow (AOF) through the casing. Including an in situ downhole camera system and a lab based optical comparator.



Vernier Calipers

- 2 orthogonal measurements
  - $D_{avg} = (1/2)*(d_{max}+d_{90})$
  - OAD – Orthogonal Average Diameter
- Long probe – ensure probes pass completely through hole



Downhole Video Perforation Measurements

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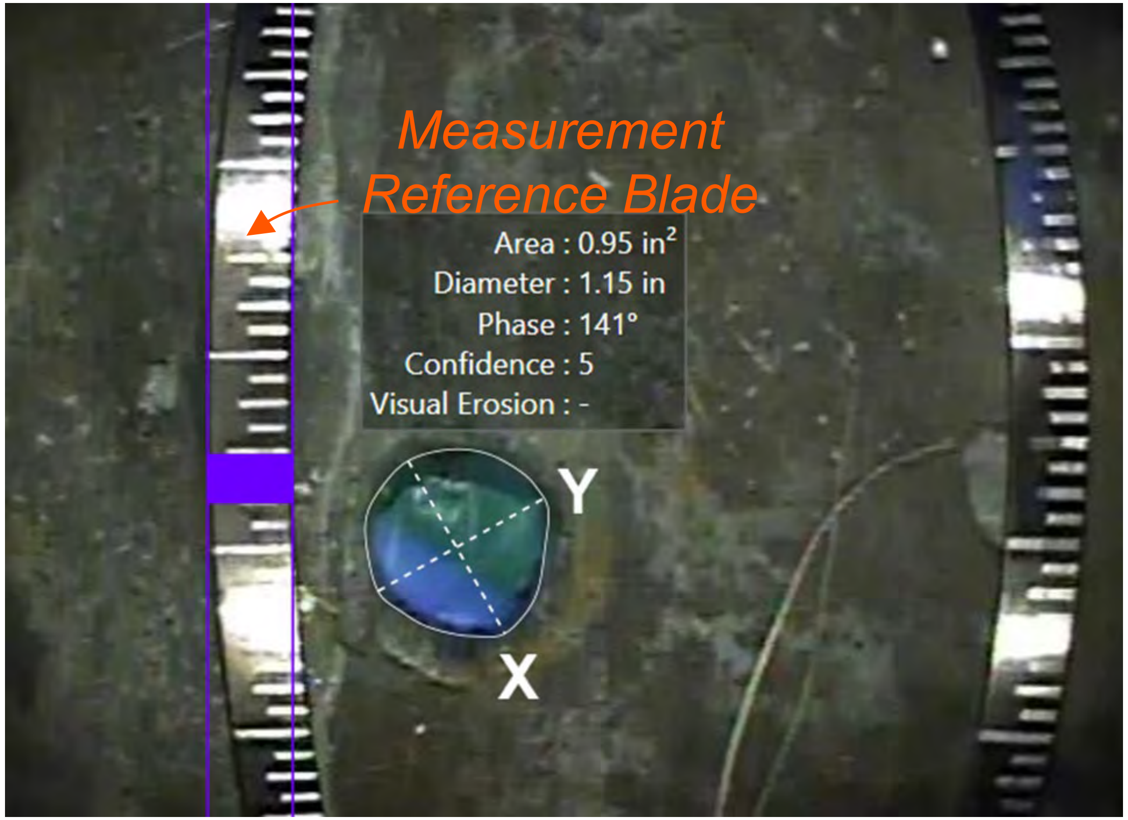
Camera with 'Reference Blades' Used During Project



Motor used to rotate a side-viewing camera to directly face the phased perforations.

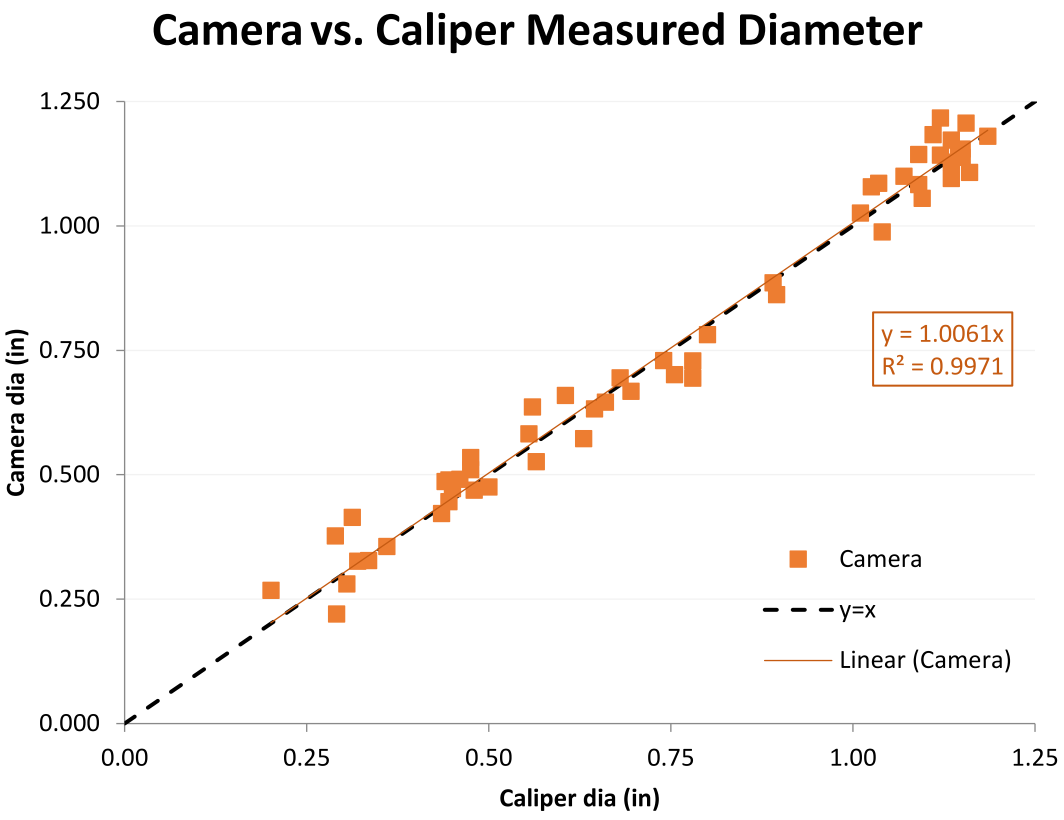
Measurement Reference Blades with known arm widths are positioned in the field of view of camera and act as a 'yard-stick' to provide a calibrated pixel size for each measurement.

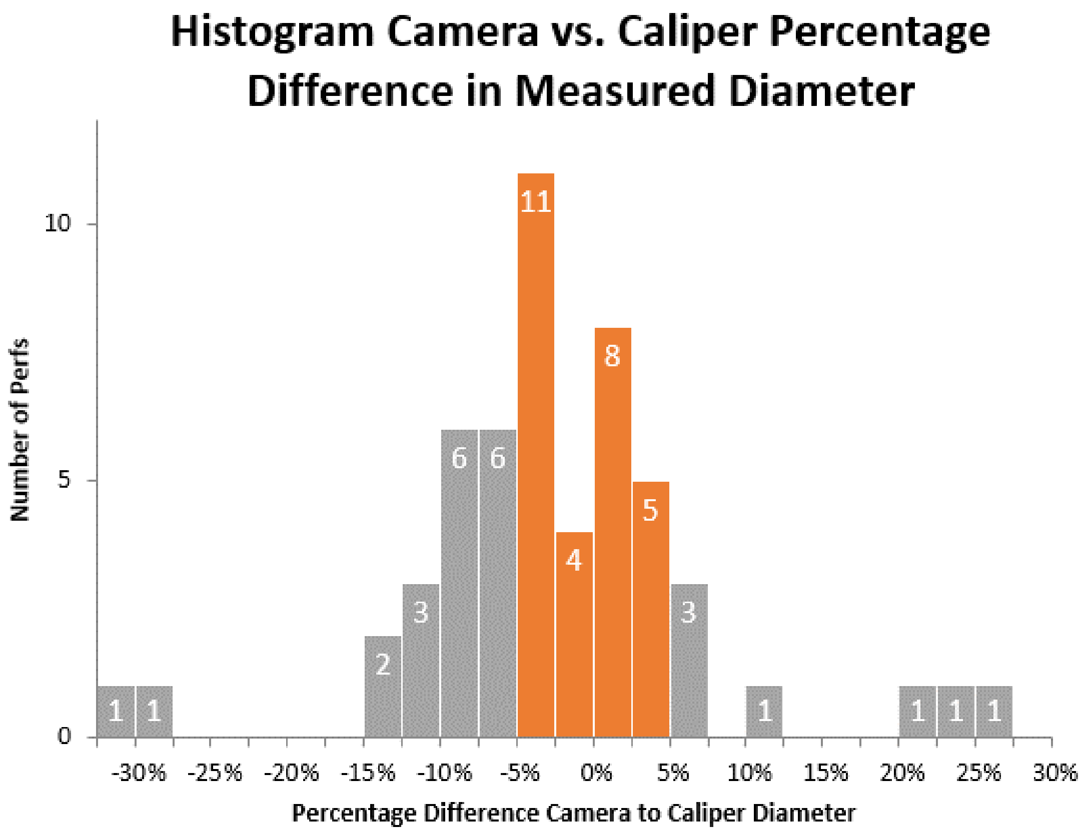
Diameter measurements are made by counting the number of pixels along the perforation axes and multiplying by the calibrated size of each pixel.

(x_i, y_i), $i = 1, 2, \ldots, n$ are the vertices (or "corners") of the polygon. Result is multiplied by calibrated pixel size to provide an area measurement in in^2.

Camera versus Caliper Diameter Comparison

On average a very close agreement exists between Camera and Caliper measured hole diameters. Individual values differ over a range of -0.86" to 0.10", with the standard deviation of the difference being 0.04". More than half of the measured values agree within +/- 5%, but a small number of large outliers were recorded.



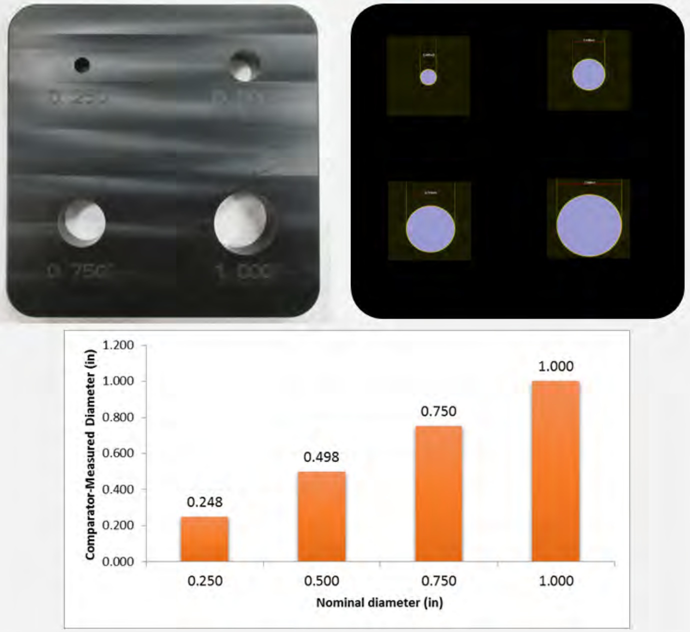


Optical Comparator

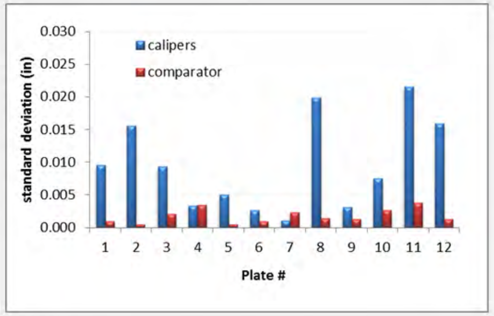
- More repeatable, and operator-independent, vs. caliper method

Precise

Accurate



Repeatable



12 different casing plate holes measured, by:

- 3 different operators, using calipers
- comparator (3 different measurements)

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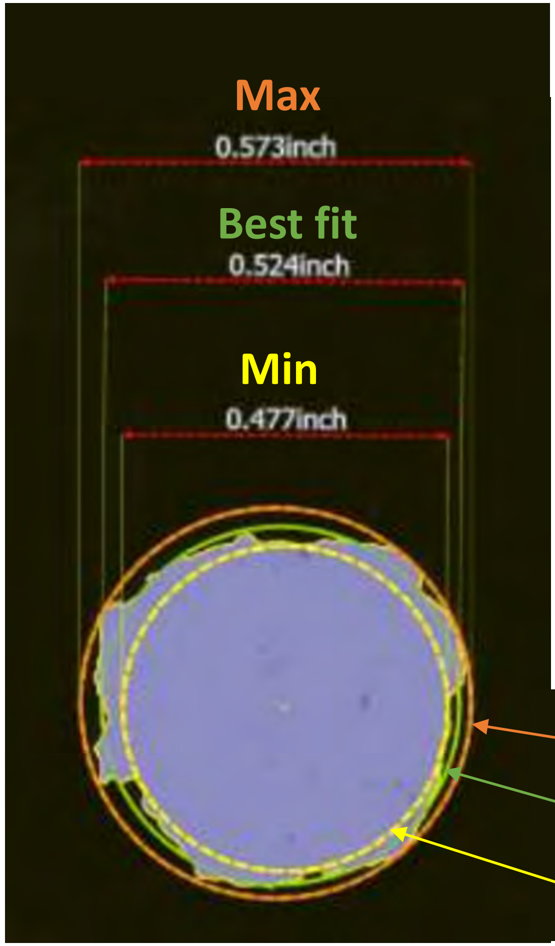
Optical Comparator (2)

- Light path through hole
- Sample placement is important
  - (hole axis // light path)
- Hole area, perimeter, diameter

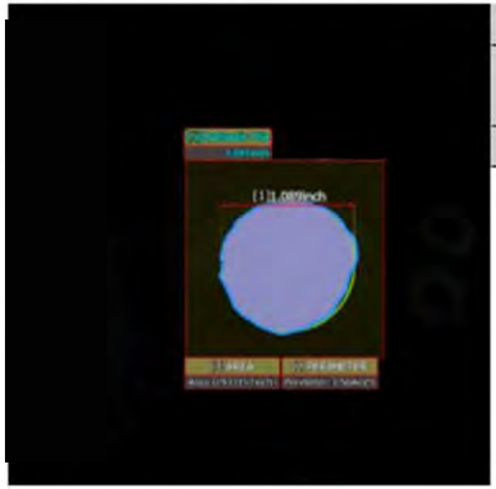
Optical Comparator (3)

Outputs

- Image
- Direct measurements
  - Area
  - Perimeter
- Additional outputs
  - Diameter (best fit)
  - Diameter (max)
  - Diameter (min)



HOLE DATA REPORT



DATE & TIME
PROJECT NUMBER
TEST NUMBER
PART DESCRIPTION

[Measurement results]

No.	measurement item	mes. value	units
1	Best Fit Dia	1.089	inch
2	PERIMETER	3.584	inch
3	AREA	0.933157	$inch^2$

Optical Comparator (4)

- Representative Diameters
  - Best fit * → $D_{bf} = f(x_n, y_n)$............. *least squares method*
  - Equivalent ** → $D_{eq} = sqrt(4A/\pi)$....... *assumes circle*
  - Hydraulic ** → $D_h = 4A/P$ ***........ *takes into account perimeter*
- Circularity → $C = 4\pi A/P^2$ ***....... *C≤1*

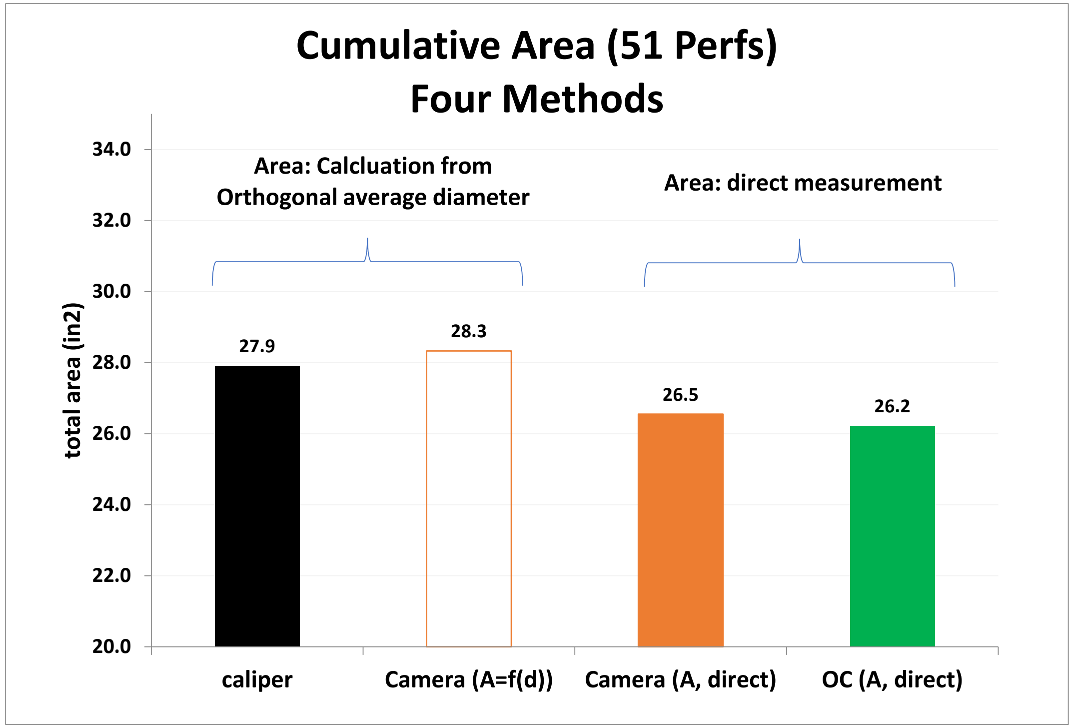
**** Ref: URTeC 3723896*

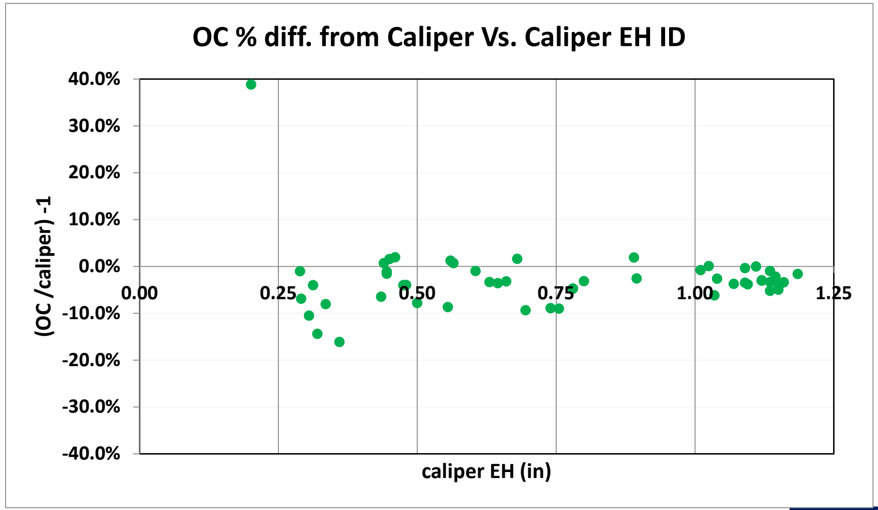
For a circle, C = 1. Values for other simple shapes:

a) 1x2 rectangle, 0.698.
b) equilateral triangle, 0.605.
c) Square, 0.785 and
d) Hexagon, 0.907.

** Machine output*

*** can be calculated post-measurement*



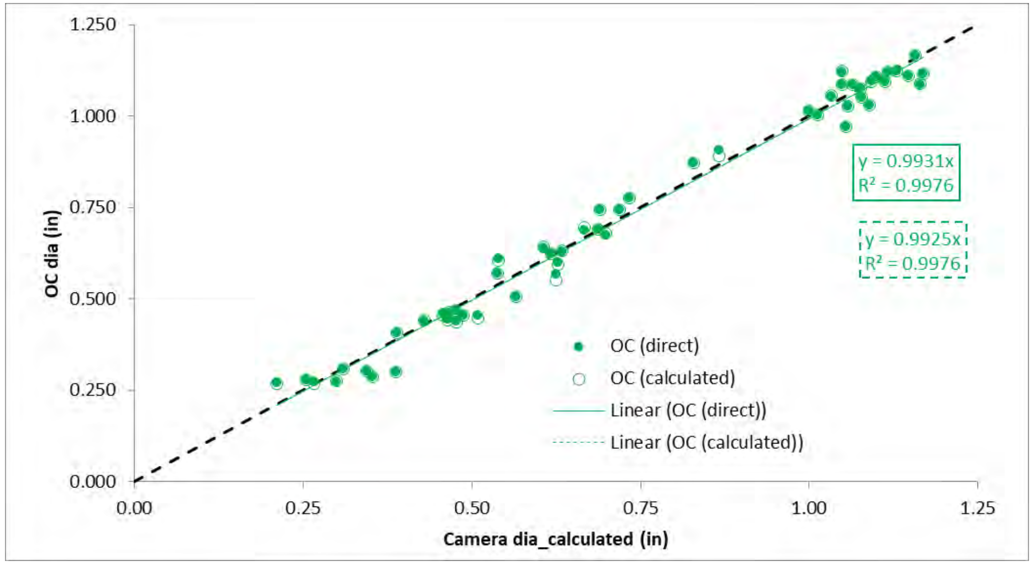


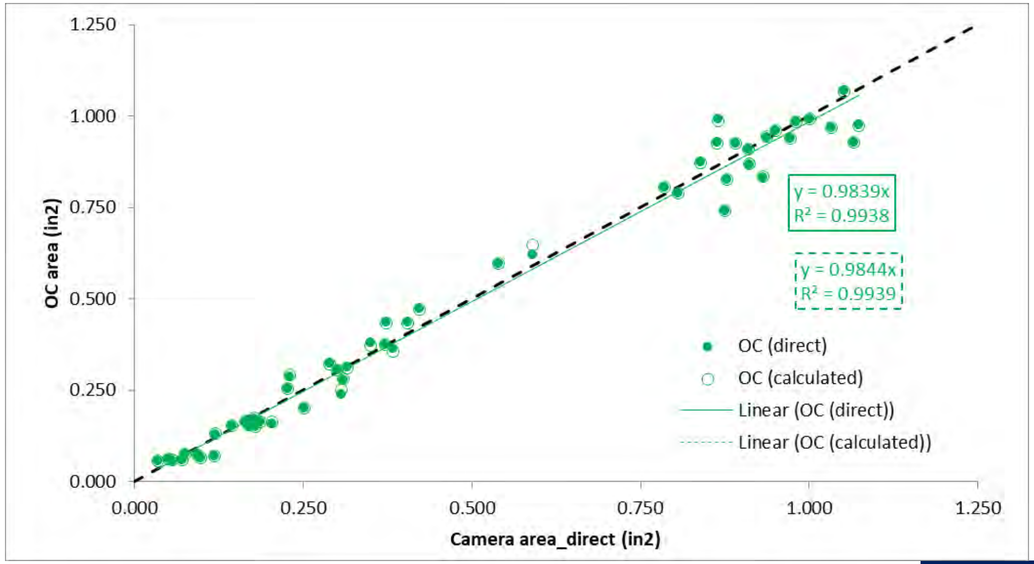
- Orthogonal average diameter (OAD) methods overestimate diameters and areas compared to direct area measurements
  - Caliper (OAD)
  - Camera OAD
  - Average Overestimated area is 6.57%

Overestimated Area of OAD vs. Area direct	
caliper vs Camera direct	5.10%
caliper vs OC direct	6.44%
camera (OAD) vs camera direct	6.70%
camera (OAD) vs OC direct	8.06%
average	6.57%

- Diameter overestimate trend exists over entire range of perforation diameters
  - Average diameter overestimate: 3.0% for caliper vs OC direct.

Optical (OC): Direct Measurement & Calculated Diameters and Areas





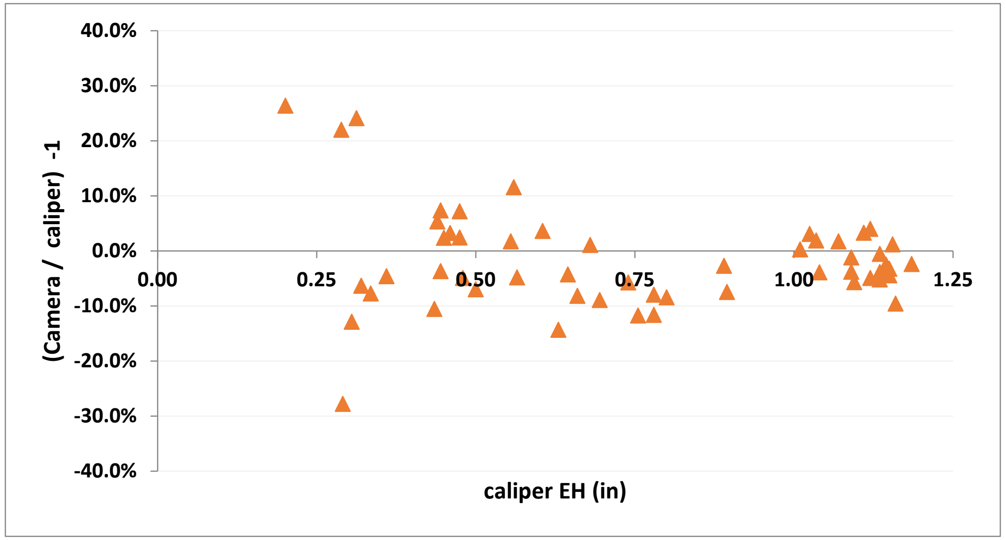
- The two different methods of OC diameter determination are in very close agreement.
  1. OC (direct) is from the best fit diameter
  2. OC (calculated) is calculated from direct area measurement

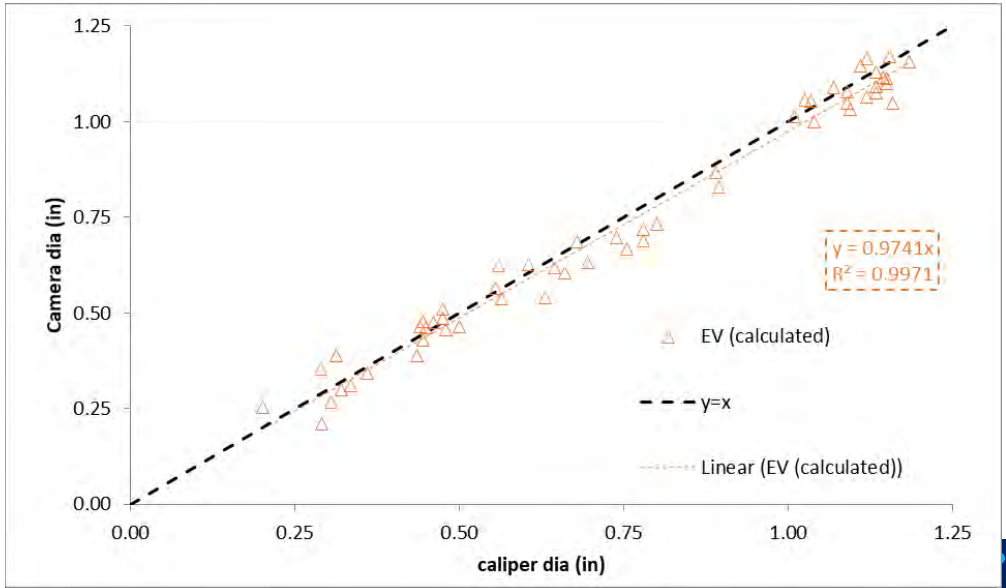
  - Slope OC direct: 0.9931 (R^2 = 0.9976)
  - Slope OC calculated: 0.9925 (R^2 = .9976)

- Similar very close agreement on OC area determination.

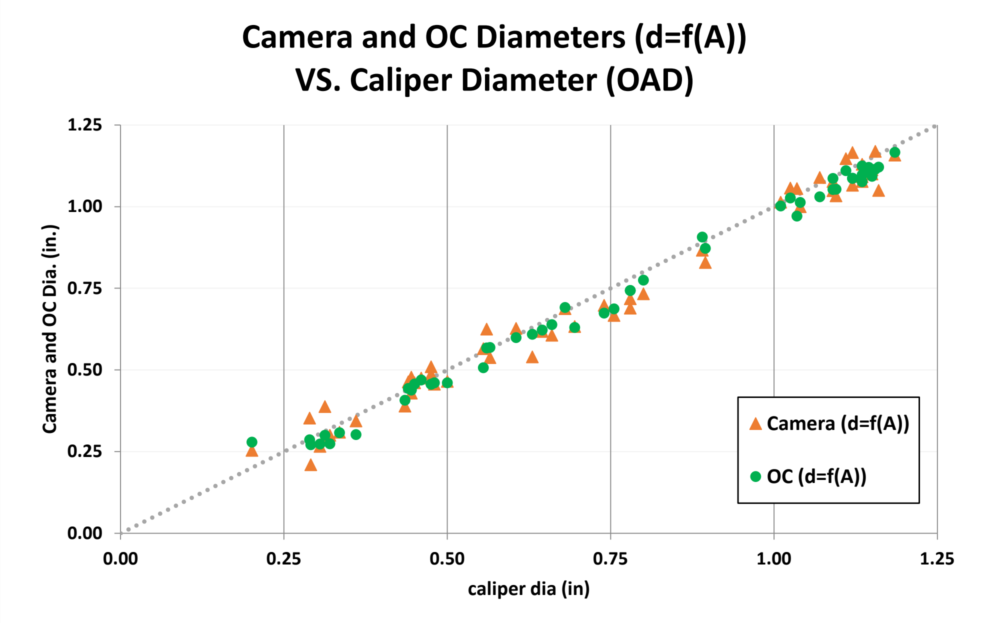
  - Slope OC direct: 0.9839 (R^2 = 0.9938)
  - Slope OC calculated: 0.9844 (R^2 = .9939)

Camera ID's calculated from Direct Area Vs. Caliper (OAD)



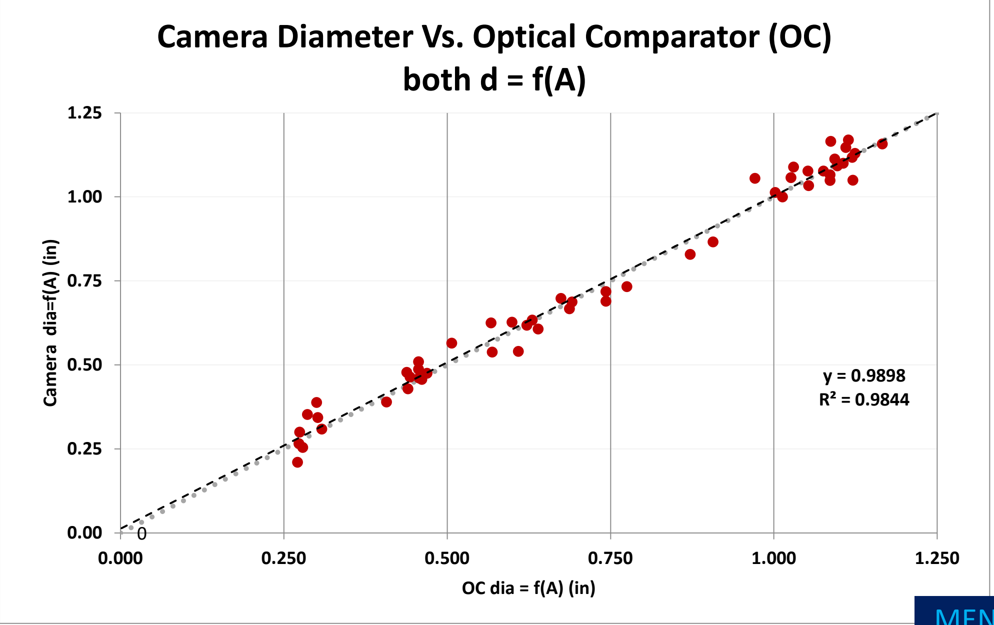


- Diameter overestimate trend exists over entire range of perforation diameters
  - Average diameter overestimate: 1.8% for caliper vs Camera direct.
  - Some data shows underestimate of ID
    - Smaller ID's variances may indicate some limitations of technique.
- Smaller ID's can exhibit higher % differences than larger ID's.



Camera and Optical Comparator (OC) Comparison of techniques VS. Caliper

- ID's as a function of direct measurement of area
- Both the Camera and the OC show smaller ID's as compared to the caliper.
- Both the camera and the OC are in close agreement.



Camera Vs. Optical Comparator (OC)

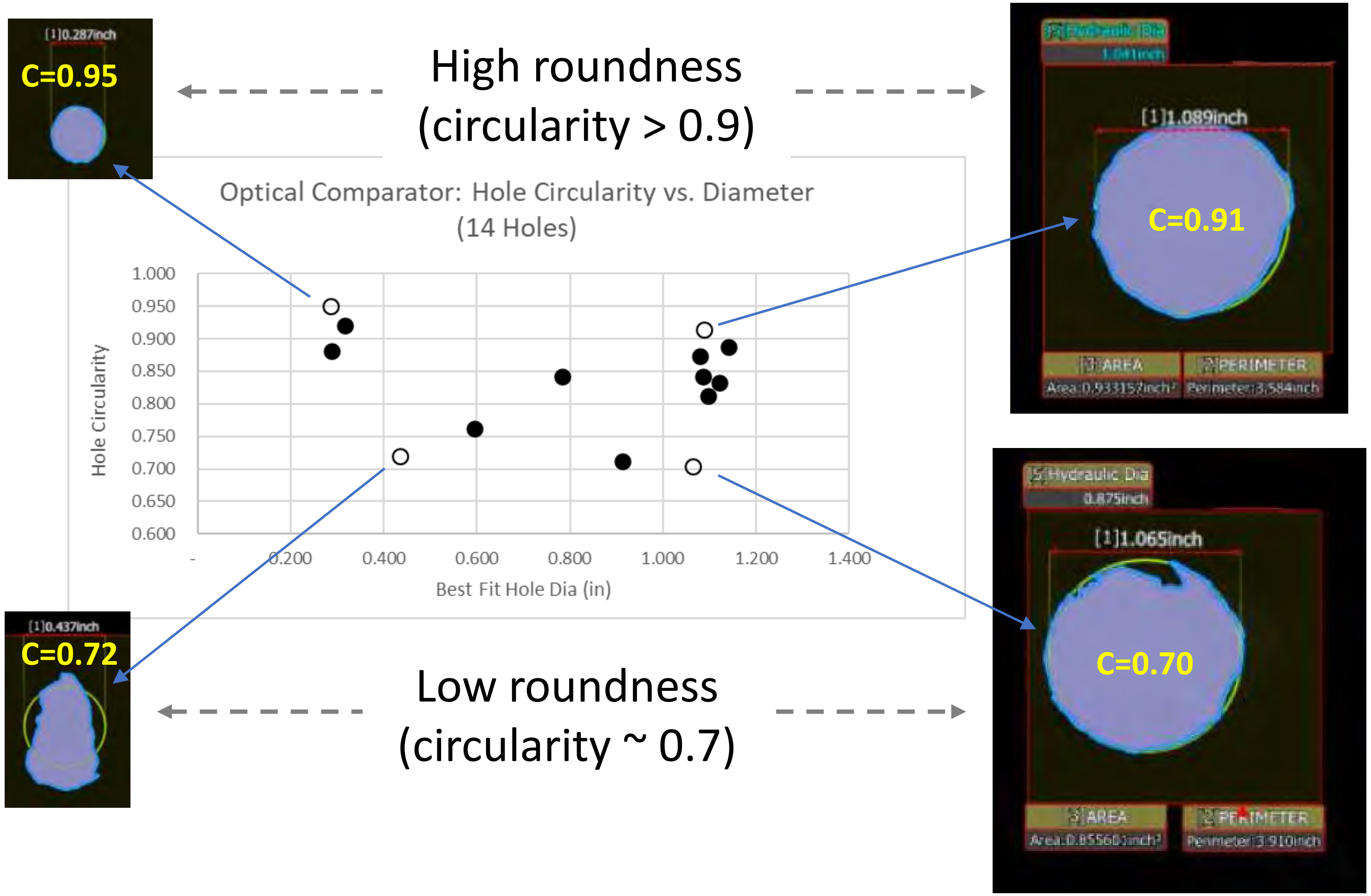
- ID's as a function of direct measurement of area
- Both the Camera and the OC show very close agreement.

- The trend line lies almost directly over the slope line of 1.0
  - trend slope of 0.9898 and R^2 of 0.9844

Hole Circularity (1)

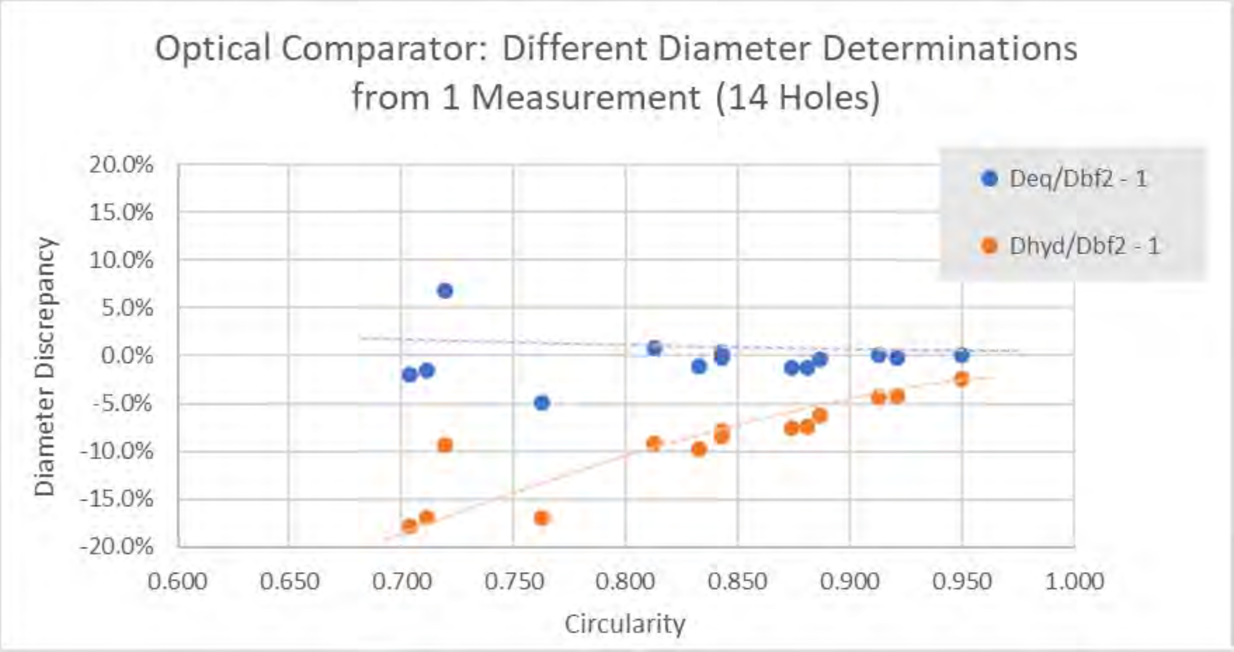
$$C = 4\pi A/P^2$$

- As C→1, holes are visually "rounder"
- Holes with low C values are either non-round, or have features/protrusions



Hole Circularity (2)

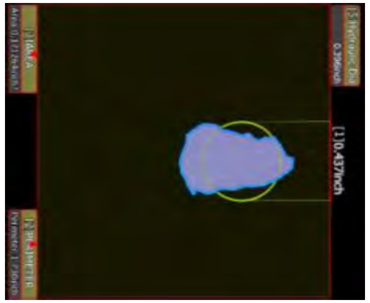
- As C→1, different diameter determination methods converge
- *Even for holes with C<<1, equivalent and best fit diameters agree quite well*



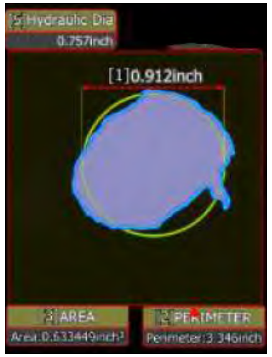
Recall from earlier slide:

- Representative Diameters
  - Best fit * → $D_{bf} = f(x_n, y_n)$............. *least squares method*
  - Equivalent ** → D_{eq} = sqrt(4A/π)....... *assumes circle*
  - Hydraulic ** → $D_h = 4A/P$ ***......... *takes into account perimeter*
- Circularity → $C = 4\pi A/P^2$ ***........ *C≤1*

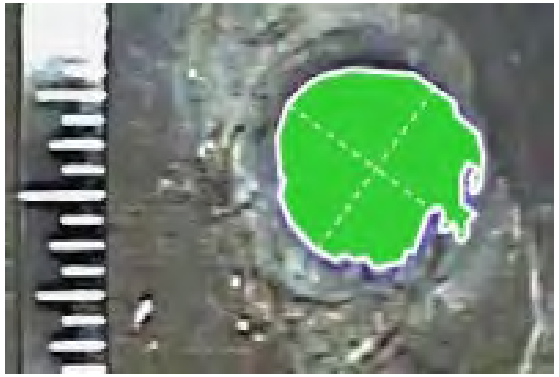
Comparison of Camera vs OC Images

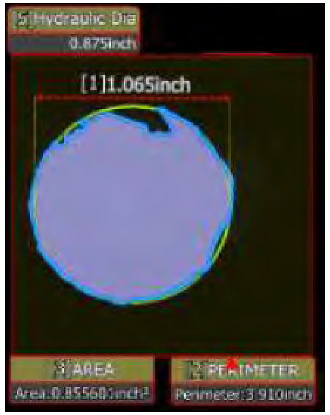


Shot #	Camera				Caliper		Optical Comparator		
	Davg	Deq	Adirect	Acalc	Davg	Acalc	Dbestfit	Deq	A_{direct}
102	0.469	0.457	0.164	0.173	0.48	0.181	0.437	0.467	0.171

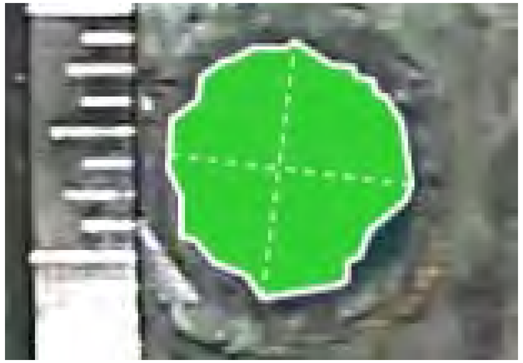


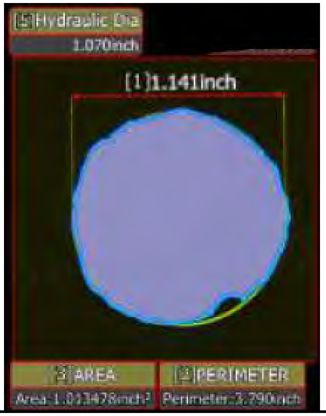
Shot #	Camera				Caliper		Optical Comparator		
	Davg	Deq	Adirect	Acalc	Davg	Acalc	Dbestfit	Deq	A_{direct}
111	0.885	0.866	0.589	0.616	0.89	0.622	0.912	0.898	0.633





Shot #	Camera				Caliper		Optical Comparator		
	Davg	Deq	Adirect	Acalc	Davg	Acalc	Dbestfit	Deq	A_{direct}
116	1.143	1.077	0.911	1.026	1.09	0.933	1.065	1.044	0.856





Shot #	Camera				Caliper		Optical Comparator		
	Davg	Deq	Adirect	Acalc	Davg	Acalc	Dbestfit	Deq	A_{direct}
106	1.107	1.049	0.864	0.963	1.16	1.057	1.141	1.136	1.013

Summary

Conclusions

- Orthogonal average diameter (OAD) methods overestimate diameters by ~3% (compared to area-based diameter methods).
- OAD methods overestimate area by ~6.6% (compared to direct area measurements).
- Direct area and perimeter measurements are data rich and more accurate when compared to OAD methods and allow calculation of Circularity and Hydraulic Diameter parameters.
- Camera and OC technologies allow for direct measurement of areas, with minimal or no human. intervention, reducing the variability of the measurements.
- Strong correlation between the lab OC and downhole camera measurements.
- OAD from all the technologies are similar, but yield inflated areas by calculation.

Suggested Further Work

- Compare “inside out” OC measurements to the camera measurements.
- Trial additional technologies (handheld laser scanners, downhole acoustic scanners, other DH Cameras) and compare their results.
- Incorporate area and / or directly measured data into API standards.
- Evaluate 2D vs 3D technologies.

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Q&A

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