

Estimating Remaining Life of Heat Exchangers using Extreme Value Analysis (EVA)

Includes a free online app!

Heat Exchangers

Heat exchangers are integral to operations in oil & gas, chemical and power generation industries.

A typical shell and tube heat exchanger can house anywhere between a few hundred tubes to more than 5000 tubes.

The wall thickness of these tubes diminishes over time due to corrosion.

Thickness readings offer an estimate of the remaining life. The thinnest tube represents the “weakest link” and dictates the remaining life of the heat exchanger.

Measuring Wall Thickness

Wall thickness of heat exchanger tubes are typically measured using the Internal Rotary Inspection System (IRIS) method.

It is an ultrasonic non-destructive method, and is able to detect corrosion and pitting on the tube surface along with thickness measurements.

This method requires the tubes to be thoroughly cleaned before inspection. It also requires a constant water supply as a couplant.

IRIS can be very time consuming, especially when there are thousands of tubes to inspect, delaying restart after a shutdown.

Can statistics come to the rescue?

Extreme Value Analysis

Extreme Value Analysis (EVA) is a statistical method that can be used to estimate the wall thickness of the thinnest tube in a heat exchanger based on measurements from a sample of tubes (20 to 30 tubes).

Wang (2006) presented a paper at a conference of The American Society of Mechanical Engineers (ASME) demonstrating this type of analysis.

Wall thickness measurements from a sample of tubes are taken and the minimum thickness from each tube is recorded.

A Gumbel distribution is then fit to the recorded values and extrapolation is used to estimate the most extreme value (i.e. thinnest tube in the entire heat exchanger).

Extreme Value Analysis

Technical details regarding model parameter estimation, uncertainty quantification and goodness-of-fit assessments can be found in the Appendix to this document.

EVA is available in commercial Integrity Management System (IMS) softwares (Cenosco, 2025).

I built a web application that can perform EVA using the R open source software, based on the work by Wang (2006).

The rest of this document demonstrates how to use this online application to perform EVA for a heat exchanger remaining life calculation.

Selecting Tubes to Sample

The sample of tubes selected for measurement must be representative of the population of tubes in the heat exchanger. There should be no bias towards any one particular part of the exchanger i.e. convenience sampling.

If there is any evidence to suggest that corrosion behaviour might be different in different areas (eg: top vs bottom, inlet vs outlet), then stratification must be employed. Each strata should be analyzed separately.

It is important that the selected sample of tubes for EVA come from a homogenous population for unbiased results.

Selecting tubes from a non-homogenous population can lead to misleading conclusions.

EVA Online App

Extreme Value Analysis

Calgary Analytics

Input

Results

Plots

Help

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Data Input

Upload Wall Thickness Data (.txt file): ⓘ

Browse... No file selected

OR

Minimum Wall Thickness Values (one per line):

Enter minimum wall thickness values, one per line...

Nominal Wall Thickness:

0.095

Renewal Thickness:

0.04

Total Number of Tubes (N):

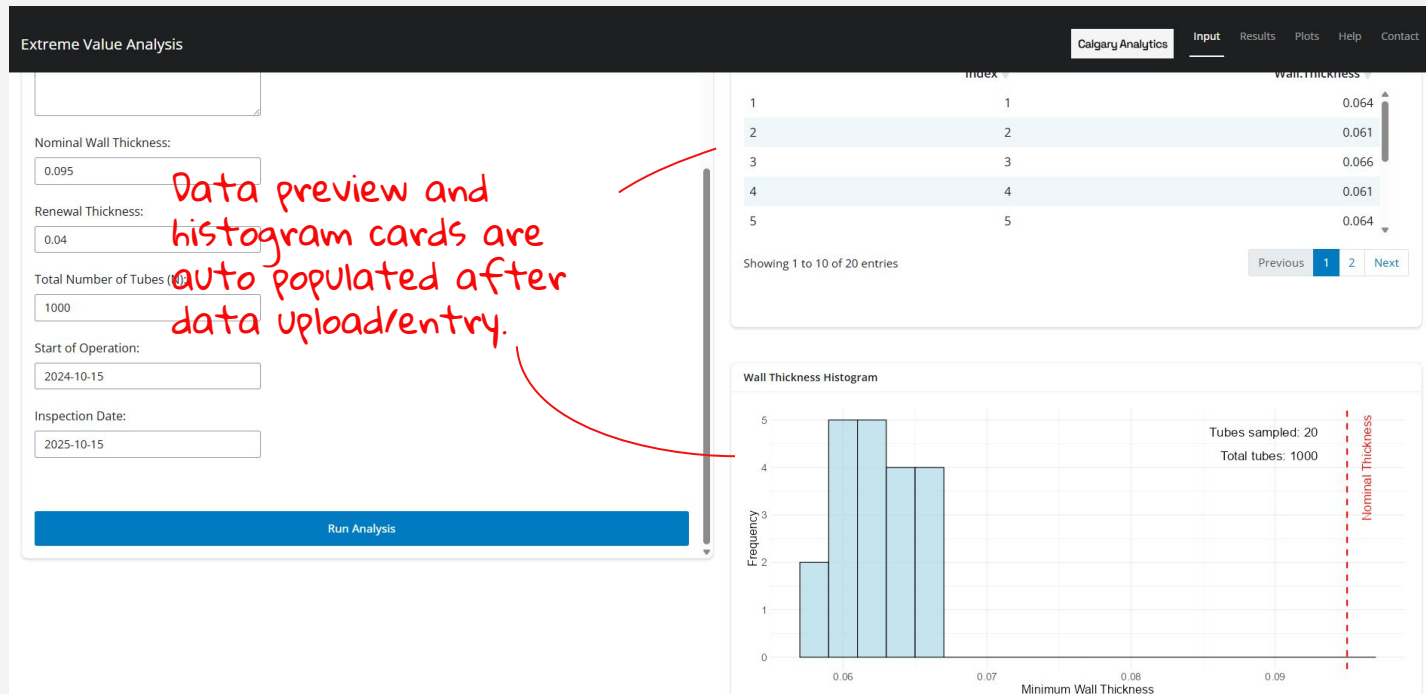
1000

Data Preview

Wall Thickness Histogram

2 ways to input data: upload a .txt file or manually Input values.
Note that the .txt file must contain one measurement per line.

EVA Online App



EVA Online App

Extreme Value Analysis

Calgary Analytics Input Results Plots Help Contact

Nominal Wall Thickness:
0.095

Renewal Thickness:
0.04

Total Number of Tubes (N):
1000

Start of Operation:
2024-10-15

Inspection Date:
2025-10-15

Run Analysis

Index Wall Thickness

1	1	0.064
2	2	0.061
3	3	0.066
4	4	0.061
5	5	0.064

Showing 1 to 10 of 20 entries

Previous 1 2 Next

Wall Thickness Histogram

Frequency

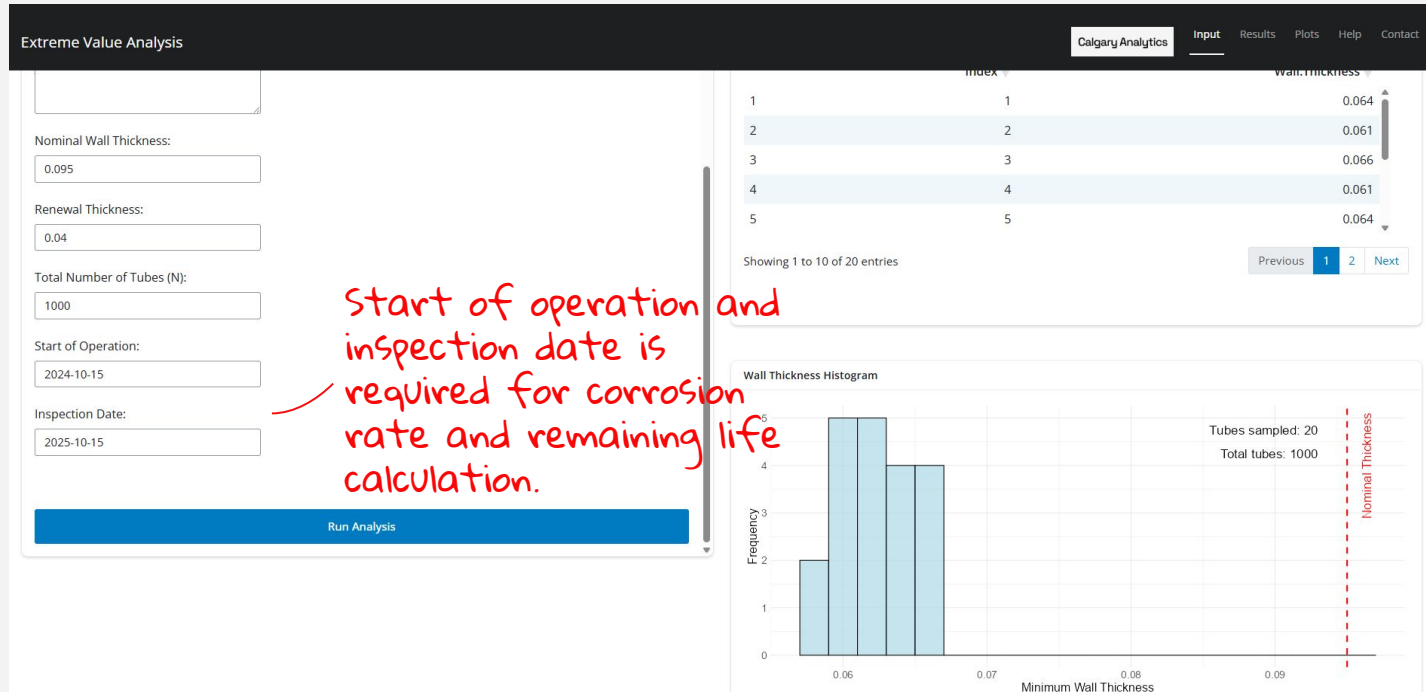
Minimum Wall Thickness

Tubes sampled: 20
Total tubes: 1000

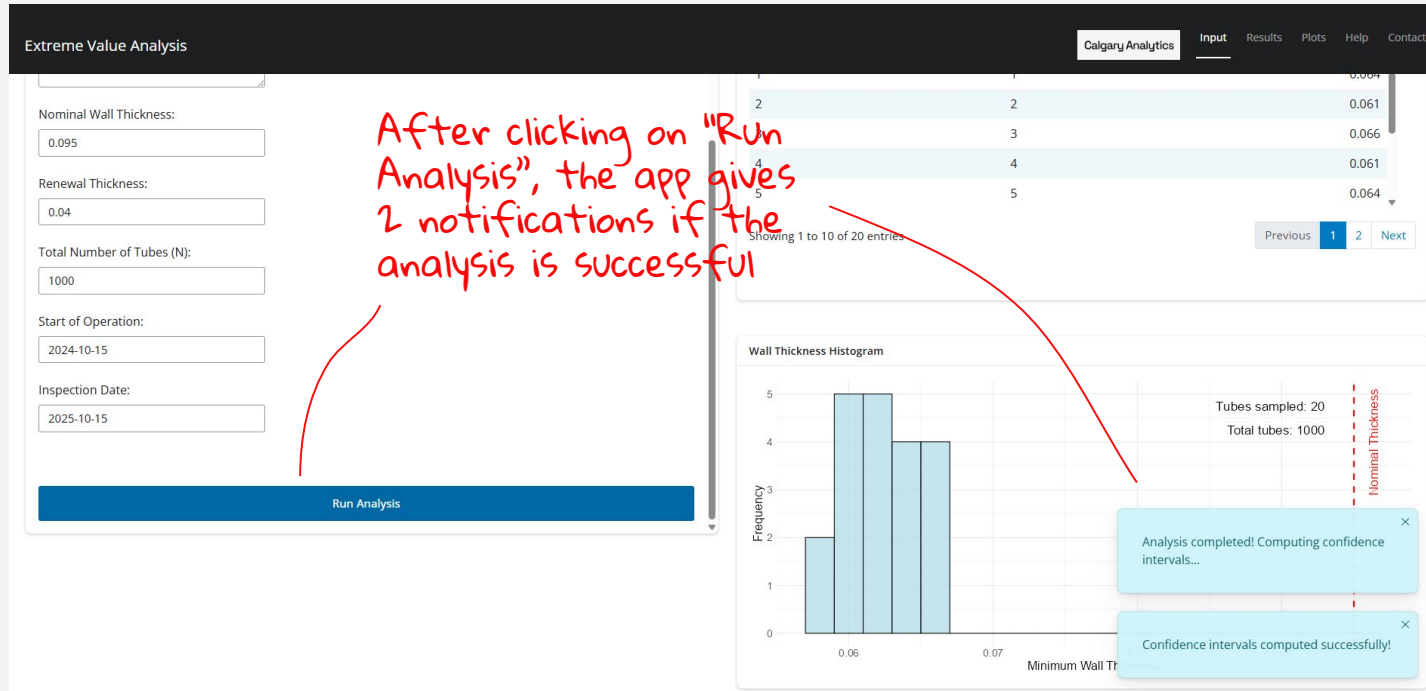
Nominal Thickness

The screenshot displays the 'Extreme Value Analysis' web application. On the left, there is an input form with fields for 'Nominal Wall Thickness' (0.095), 'Renewal Thickness' (0.04), 'Total Number of Tubes (N)' (1000), 'Start of Operation' (2024-10-15), and 'Inspection Date' (2025-10-15). A red bracket groups these fields with a handwritten note: 'Renewal thickness is the minimum acceptable wall thickness for heat exchanger operation'. To the right of the input form is a table with columns 'Index' and 'Wall Thickness', showing the first five entries of a 20-entry dataset. A red arrow points from the 'Renewal Thickness' input field to the table with the handwritten note: 'Ensure rest of the data is input correctly.' Below the table is a 'Wall Thickness Histogram' showing the frequency distribution of wall thicknesses. The x-axis is 'Minimum Wall Thickness' (0.06 to 0.09) and the y-axis is 'Frequency' (0 to 5). A vertical red dashed line indicates the 'Nominal Thickness' at 0.095. Text on the histogram states 'Tubes sampled: 20' and 'Total tubes: 1000'.

EVA Online App



EVA Online App



EVA Online App

Click "Results"

Extreme Value Analysis

Calgary Analytics

InputResultsPlotsHelpContact

Gumbel Distribution Fit

Location parameter: 0.031082
Scale parameter: 0.002301

Parameters estimated using maximum likelihood.

Goodness of Fit Tests

Test	P-value
Kolmogorov-Smirnov	0.952
Anderson-Darling	0.915

Higher p-values indicate a better fit. If the p-value is less than 0.05, we reject the null hypothesis (at the 5% alpha level) that the data follows a Gumbel distribution and conclude that the fit is not adequate.

Minimum Wall Thickness Estimate

Estimated maximum wall loss for 1000 tubes: 0.047 units
Standard error: 0.003

Estimated minimum wall thickness based on the lower bound of a 95% confidence level is 0.042 units.

Minimum Wall Thickness Estimates:				
	99%	95%	90%	80%
Lower Bound	0.039	0.042	0.043	0.044

Note: The estimates must only be used after considering the results of the goodness of fit

Corrosion Rate and Remaining Life Estimates

Corrosion Rates (units/year):

99%	95%	90%	80%
0.056	0.053	0.052	0.051

Remaining Life (years):

99%	95%	90%	80%
-0.01	0.03	0.05	0.08
N/A	2025-10-28	2025-11-05	2025-11-14

Negative remaining life indicates that the estimated minimum wall thickness is less than the renewal thickness.

Renewal Thickness: 0.04 units
Start of Operation: 2024-10-16
Inspection Date: 2025-10-16

Estimated minimum wall thickness at 95% CI

Estimated minimum wall thickness at other confidence levels

EVA Online App

Click "Results"

The screenshot displays the EVA Online App interface with a dark header bar. The header contains the text "Extreme Value Analysis" on the left and a navigation menu on the right with links: "Calgary Analytics", "Input", "Results" (highlighted with a red underline and a red arrow pointing to it from the text "Click 'Results'"), "Plots", "Help", and "Contact".

The main content area is divided into four panels:

- Gumbel Distribution Fit:** Shows location and scale parameters, and a note that parameters were estimated using maximum likelihood.
- Minimum Wall Thickness Estimate:** Displays the estimated maximum wall loss for 1000 tubes (0.047 units) and the standard error (0.003). It also shows the estimated minimum wall thickness based on the lower bound of a 95% confidence level (0.042 units). A table of Minimum Wall Thickness Estimates is provided.
- Goodness of Fit Tests:** Shows p-values for Kolmogorov-Smirnov (0.952) and Anderson-Darling (0.915) tests. A note explains that higher p-values indicate a better fit.
- Corrosion Rate and Remaining Life Estimates:** Displays corrosion rates (units/year) and remaining life (years) for different confidence levels (99%, 95%, 90%, 80%). It also includes a note about negative remaining life indicating that the estimated minimum wall thickness is less than the renewal thickness.

Handwritten red text is overlaid on the screenshot, stating: "For the example shown, note that the estimated minimum wall thickness in 1000 tubes is 0.042 units, whereas the minimum thickness in the sample of 20 tubes is 0.057 units." A red line connects this text to the "Minimum Wall Thickness Estimate" panel.

EVA Online App

Click "Results"

The screenshot displays the EVA Online App interface for Extreme Value Analysis. The top navigation bar includes 'Calgary Analytics', 'Input', 'Results' (highlighted with a red arrow), 'Plots', 'Help', and 'Contact'. The main content area is divided into four panels:

- Gumbel Distribution Fit:** Shows location and scale parameters, and a note that parameters were estimated using maximum likelihood.
- Goodness of Fit Tests:** Displays p-values for Kolmogorov-Smirnov and Anderson-Darling tests, with a note explaining that higher p-values indicate a better fit.
- Minimum Wall Thickness Estimate:** Provides an estimated maximum wall loss and a standard error, along with a table of minimum wall thickness estimates at different confidence levels.
- Corrosion Rate and Remaining Life Estimates:** Shows corrosion rates and remaining life estimates at different confidence levels, along with a note about negative remaining life and a table of renewal thickness and inspection dates.

Handwritten red annotations highlight specific areas: 'Check p-values of the GOF tests' points to the Goodness of Fit Tests panel; 'Corrosion rates and remaining life' points to the Corrosion Rate and Remaining Life Estimates panel; and 'End-of-life date is calculated from the inspection date onwards.' points to the inspection date in the Corrosion Rate and Remaining Life Estimates panel.

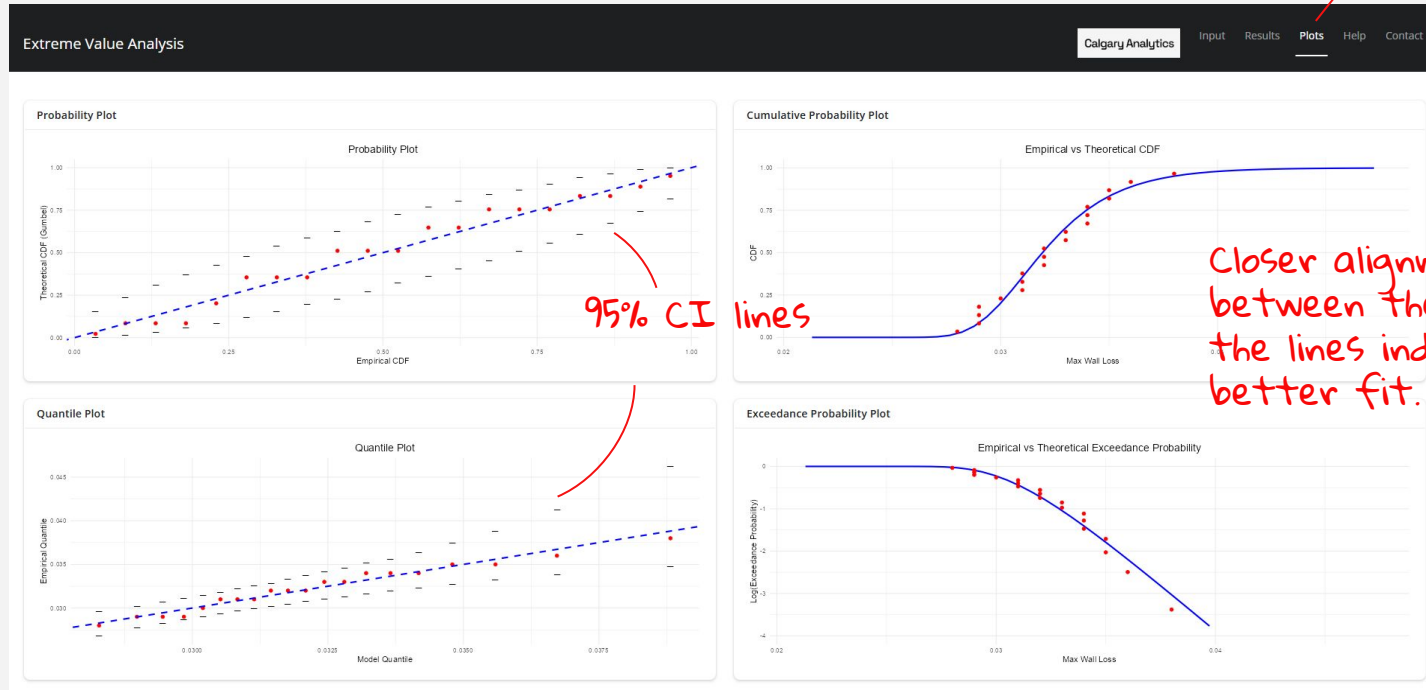
Minimum Wall Thickness Estimates:	99%	95%	90%	80%
Lower Bound	0.039	0.042	0.043	0.044

99%	95%	90%	80%
0.056	0.053	0.052	0.051

99%	95%	90%	80%
-0.01	0.03	0.05	0.08
N/A	2025-10-28	2025-11-05	2025-11-14

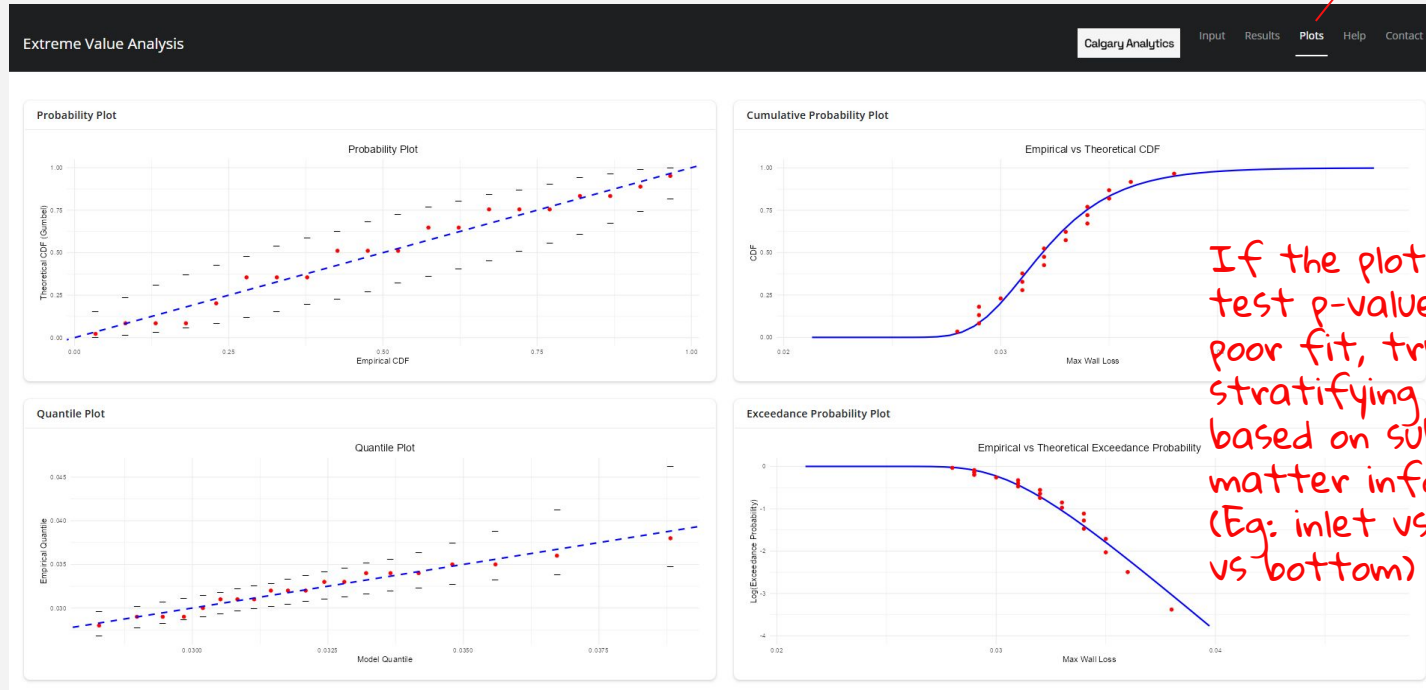
EVA Online App

Click "Plots"



EVA Online App

Click "Plots"



If the plots and GOF test p-values indicate a poor fit, try stratifying your data based on subject matter information. (Eg: inlet vs outlet, top vs bottom)

Appendices

Appendix A: Model Parameter Estimation

Appendix B: Uncertainty Quantification

Appendix C: Goodness-of-Fit Assessment

Appendix D: Potential Improvements

Appendix E: References

Appendix F: Credits

Appendix A: Parameter Estimation

Wall loss (nominal minus measured thickness) from each sampled tube is recorded.

The maximum wall loss readings from each sample is then fit to a Gumbel extreme value distribution.

The Cumulative Distribution Function (CDF) of a Gumbel Distribution is given by:

$$F(x) = \exp\left(-\exp\left(-\frac{x-\lambda}{\delta}\right)\right)$$

The parameters λ (location) and δ (scale) can be estimated via maximum likelihood, method of moments or least squares estimation.

Appendix A: Parameter Estimation

The EVA calculator uses maximum likelihood to estimate the parameters using the “evd” package in R.

Maximum likelihood tends to be more accurate, but is slightly more computationally intensive as compared to Method of Moments and Least Squares.

In the rare case that the maximum likelihood estimation fails to converge or the information matrix is singular, one can revert to other estimation methods.

Not currently implemented in the app

Appendix A: Parameter Estimation

Once the parameters of the model are estimated, the maximum wall loss estimated using the “return level” method is given by:

$$x_N = \delta \cdot \left(-\ln \left(-\ln \left(\frac{N-1}{N} \right) \right) \right) + \lambda$$

Where N is the total number of tubes in the heat exchanger.

The confidence interval for the above quantile is obtained using the Expected Information matrix and the Delta method.

Appendix B: Uncertainty Quantification

The ASME paper (Wang, 2006) uses the inverse of the Expected Fisher Information matrix as an estimate of the variance-covariance matrix.

The “evd” package in R uses the Observed Fisher Information matrix to estimate the variance-covariance matrix.

Both approaches are valid, but the EVA calculator uses the Expected Information matrix to stay consistent with the ASME paper (Wang, 2006).

Appendix C: Goodness-of-Fit

Goodness of fit is assessed using two statistical tests - Kolmogorov-Smirnov and Anderson-Darling.

Null Hypothesis: The recorded data follows the specified distribution (i.e. Gumbel).

Alternate Hypothesis: The recorded data does not follow the specified distribution (i.e. Gumbel).

The EVA calculator shows the p-values for both the tests in the “Results” tab. Higher p-values indicate a better fit.

It is important not to rely only on the statistical tests. The diagnostic plots must also be assessed.

Appendix C: Goodness-of-Fit

Diagnostic plots like the probability plot, quantile plot and the exceedance probability plots are displayed in the “Plots” tab.

These plots aid in visually assessing the quality of the fit. A good alignment between the points and the line indicates a good fit.

Additional details about these plots can be found in the IMS Handbook on the Cenosco (2025) website.

If the plots and the statistical tests indicate a bad fit, consider stratification.

Appendix D: Potential Improvements

1. On the rare occasion that maximum likelihood estimation fails, method of moments or least squares estimation to be used. This feature is not currently implemented in the app and can be easily incorporated in the future.
2. Profile likelihood method is a more accurate method of calculating confidence intervals instead of the Wald interval (Meeker et al., 2022) or Student's t-based interval. The EVA calculator uses the Student's t-based CI. The downside to profile likelihood methods is that it can be computationally intensive.
3. If the Gumbel distribution is not a good fit, and stratification doesn't help, fitting other distributions (Nee et al., 2025) could be useful. This is not currently implemented in the app.

Appendix E: References

Wang, W. D. (2006, July 23-27). *Extreme value analysis of heat exchanger tube inspection data* [Paper presentation]. 2006 ASME Pressure Vessels and Piping Division Conference, Vancouver, BC, Canada.

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Cenosco. (2025, January 29). *Extreme Value Analysis (EVA) overview*. Cenosco IMS Handbook.

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Appendix F: Package Citations

The following R packages were used in building this EVA application.

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End