Problem Of The Month
March 1997--Coke Drum Life

Coke drums are often the large pressure vessels you see in a refinery with a drilling rig derrick sitting on the top. Coke drums are both waste disposal systems for high residual, tarry oils, and they are also significant gross margin contributors to the financial performance of refineries. Volatile fumes from the coke drums are recycled to make useful products such as gasoline and the solid material deposited in the coke drum is sold as coke for many purposes. The drilling rig on top of the drum is used with water under high pressure to fracture the solid coke bed so the coke can be removed for sale.

The Problem

Richard Boswell of Stress Engineering Services, Houston, TX presented a paper at the **1997 Energy Week Conference** (sponsored by ASME and API Technical Societies) in Houston called **Remaining Life Evaluation of Coke Drums**. His co-authors were Tom Farraro and Michael J. Sober both of CITGO Petroleum Corp.

Their paper showed both axial and hoop stresses were nearly the same (!?strange event for a pressure vessel?!) due to convolutions in the 20 foot diameter vessel which began its life as a smooth, circular cylinder. In Figure 5 of the paper, they presented the maximum axial stress in a histogram. The data consisted of 126 production cycles. The vessel is known to have a finite life. Remaining coke drum life is now a major economic issue for most refineries around the world.

The maximum stress produced in coke drums usually occurs during the quench cycle. The stress is dependent upon how the operator executes the quench cycle from ~900 degrees F to ambient temperature. Fast quench cycles produce higher stresses. Slower quench cycles produce lower stresses. Also some coke drums have major stress problems in the skirt area which support the ~20 foot diameter vessel which is ~60 feet tall.

Here is a tabulation of the stresses measured with high temperature strain gages and the number of occurrences recorded. Stresses are recorded in ksi and occurrence are counts (for example the first data point is a stress level of 12.5 ksi with 4 occurrences of this maximum stress recorded):

12.5* 4	17.5*4	22.5*14	27.5*12	32.5*17	37.5*11,
42.5*12	47.5*11	52.5*9	57.5*6	62.5*5	67.5*7,
72.5*4	77.5*3	82.5*3	87.5*3	112.5*1	

The data can be entered in WinSMITH Weibull using a frequency table format, i.e., 12.5*4--which means you'll only have 17 rows of data shown in one column. This is a very efficient method for inputting data into a spreadsheet.

Questions:

1) Which statistical distribution best describes the stresses produced during the coking cycle?

a) Weibull _______ b) Log-normal _______ c) Normal _______

2) Is the data well behaved? Base the decision on the rank regression correlation coefficient (a measure of goodness of fit). Compared the actual results to the critical correlation coefficient [ccc]. The ccc is the value expected to be obtained 90% of the time from a well behaved rank regression)?

a) Yes ____ b) No _____

3) Based on a likelihood ratio estimate, what are the 90% confidence limits for the characteristics of the "best" curve fit of the data?

a) eta, muAL, mu _________ (The measure of central tendency)

b) beta, sigF, std __________ (The shape factor for the distribution)

4) What percentage of the cycles can be expected to exceed:

20 ksi ______ 30 ksi ______ 40 ksi ______ 50 ksi ______

60 ksi ______ 70 ksi ______ 80 ksi ______ 90 ksi ______

5) For coke drums which have remaining life, if you limit the stresses to a value of "X", how would you find the remaining life of the vessel as a result of limiting the remaining peak stresses?

6) If you know the operating costs/gross margins produced by the coker, and the number of cycles remaining, how can you find the most economical operating condition to maximize operating profit based on the remaining life of coke drums?

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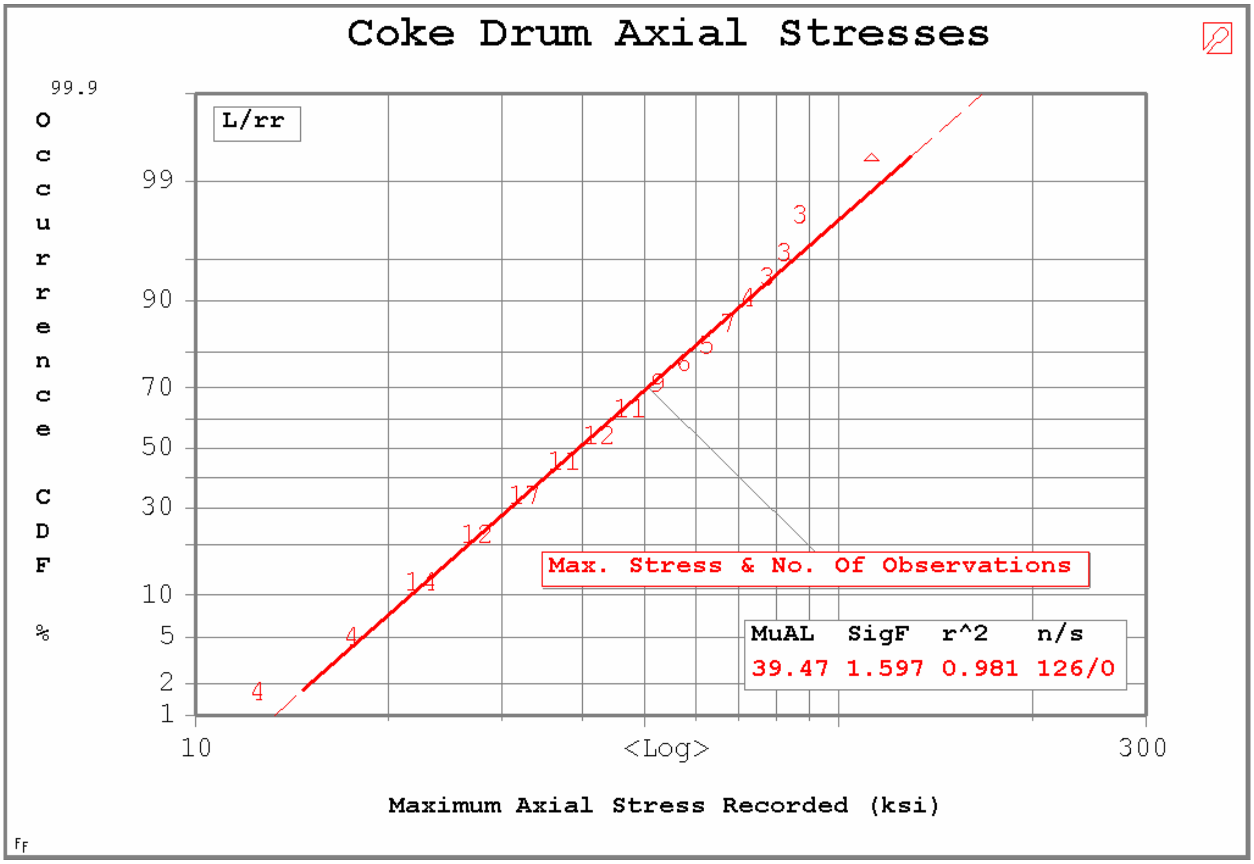
Solutions:

Start the analysis by entering the 126 data points into WinSMITH Weibull using the frequency table format. Use the rank regression technique. Click on the distribution analysis icon and find the following results for question #1.



Answer For Question #1:

Weibull Results [t0 = None, 2 Parameter]
Correlation, r = .978, r^2 = .957, ccc^2 = .9717, (r^2-ccc^2) = -.0147, (Bad!)
Characteristic Value = 48.580, Weibull Slope = 2.741, Method = rr

Weibull Results [t0 = 8.35, 3 Parameter]
Correlation, r = .987, r^2 = .976, ccc^2 = .9852, (r^2-ccc^2) = -.0092, (Bad!)
Characteristic Value = 39.668, Weibull slope = 1.954, Method = rr/t0^

LogNorm Results [t0 = None, 2 Parameter}
Correlation, r = .990, r^2 = .981, ccc^2 = .984, (r^2-ccc^2) = -.003 (Bad!, but usable!)
Log-Mean Antilog = 39.465, Std. Dev. Factor = 1.596, Method = rr

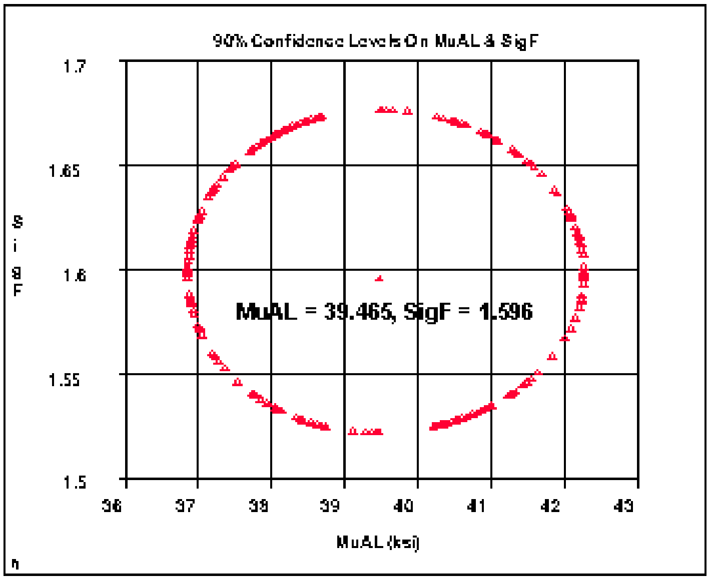
Normal+ Results [t0 = None, 2 Parameter}
Correlation, r = .974, r^2 = .949, ccc^2 = .984, (r^2-ccc^2) = -.035 (Bad!)
Mean = 43.730, Std. Deviation = 19.363, Method = rr

Choose the distribution with (r^2-ccc^2) = **largest value**. Select the l**og-normal distribution** as shown in the probability plot for coke drum axial stresses as shown on the curve along the left margin.

The actual r^2 = coefficient of determination for the coke drum axial stress lies just a smidgen outside of the desired value and this is the reason for the (Bad!) label.

Answer For Question #2:

No, the data is a little unruly. For **engineering purposes** it's an OK correlation**.** The log-normal distribution is the best of the models as the r^2 may be covered by (say) a ~92+% confidence level--but don't split hairs. The data is "course" and results are "rounded" which increases uncertainty.



Answer For Question #3:
The measure of central tendency is **MuAL = 39.465** and the shape factor **SigF = 1.596**. The zone of uncertainty, described by the 90% confidence interval, is shown in the graph to the left and you can read the results from the graph.

This elliptical-shaped curve is found by making the calculations in [WinSMITH Weibull] by clicking on 90% confidence intervals and the likelihood ratio method found under the confidence limit icon. Save the calculations to a file. Plot the file in [WinSMITH Visual] to get the results shown to the right. The 90% confidence limits are shown by the red triangles. The central triangle represents the point estimates for MuAL = 39.465 and SigF = 1.596

Answer For Question #4:
Click on the predict icon in WinSMITH Weibull when the data is in the plot with the log-normal equation activated. Verify the statistical model is log-normal by clicking on the PC icon. Input the information on the datum (such as 20 ksi), and read the information shown below to find the percentage of loads exceeding a value:

20 ksi -> **92.7%**	30 ksi -> **72.2%**	40 ksi -> **48.9%**	50 ksi -> **30.6%**
60 ksi -> **18.6%**	70 ksi -> **11.0%**	80 ksi -> **6.5%**	90 ksi -> **3.9%**

It's clear that 55ksi yield strength material for use in this fatigue environment is in serious jeopardy if long life is expected! The question is how fast the "crash and burn" will occur.

Answer For Question #5:
Find the remaining life by building a Monte Carlo model using the statistical stress distributions shown above.

a) Draw random stresses from the distribution to equal the number of cycles recorded by the unit.

b) For each random stress drawn from the simulation solve the S-N equation for the number of allowable cycles.

Remember to derate the simple S-N curve for state of stress, stress concentrations, surface finish, corrosions, etc.

Where the simulated stress is less than the "knee" of the S-N curve make the allowed number of cycles very large (say ~10E100).

c) For each simulated stress for a cycle, compute Miner's equation component (1 cycle)/(allowed cycles).

d) Sum components for Miner's equation for all iterations.

e) If the summation of Miner's equation components is greater than 1 the system fails. If less than one success.

f) Calculate reliability = successes/(successes + failures) for each group of iterations.

g) Increase the number of cycles from the present life to a future life and calculate reliability--repeat the process many times to find the central tendency.

h) Now repeat the simulations with "circuit breaker" limitations on the maximum stress --observe the increases in expected life.

Answer For Question #6:

Build several decision trees. Use the chances for success and the chances for failure (found from the simulations) to compute the gross profits for different maximum stress levels. Use the case producing the greatest net present value using a life cycle cost strategy. Consider the initial installation and the major repair costs and lost production occurring during repairs.

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Other Industry Sources For Coke Drums-

Technical comments distributed on a CD to an American Petroleum Industry conference on coke drums in May 2001 are available at http://www.cokedrum.com by Stress Engineering Services who perform experimental stress analysis and conduct extensive FEA computer studies of coke drums.

CIA Inspection Inc. performs extensive inspection of the interior of on-line delayed coke drums without blinding or scaffolding to obtain a detailed interior profile of the vessel using laser range imaging and video inspection. The site has links to coke drum related sites at http://www.cia-inspection.com/industrylinks.htm .

Refer to the caveats on the Problem Of The Month Page about the limitations of the following solution. Maybe you have a better idea on how to solve the problem. Maybe you find where I've screwed-up the solution and you can point out my errors as you check my calculations. E-mail your comments, criticism, and corrections to: Paul Barringer by  clicking here.

Technical tools are only interesting toys for engineers until results are converted into a business solution involving money and time. Complete your analysis with a

bottom line converted into $'s and time so you have answers that will interest your management team!

You can download this problem as a PDF file by clicking here.

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