

Remaining Life In Pressure Relief Valves

The Weibull User's Conference is held every two years for the purpose of describing new findings from various Weibull experts working on advancing the technology. On March 8-9, 2007 the Conference was held in Houston, Texas. [Wes Fulton](#), author of [WinSMITH Weibull](#) probability software and [WinSMITH Visual](#) Crow-AMSAA software offered the following challenge problem:

What is the remaining life in relief valves that are surviving in service after 24 months.

The Issue:

“You have 10, special purchase, high-temperature, relief valves in service. The test data for life is a Weibull model fitted to their laboratory, high temperature, time-to-failure data which indicates:

characteristic life $\eta = 72$ months and Weibull shape factor $\beta = 2.6$.

The recommended scheduled replacement interval is 2 years of service. The valves have completed 24 months of service and none have failed. The reliability for 24 months of service starting from time zero is 94.4% using the original Weibull model. You want to demonstrate a minimum reliability of 95% for continued operation. The big question for these surviving safety relief valves:

How much longer can you keep these valves in service before you need to replace them?”

Facts:

Weibull characteristic life, $\eta = 72$ months. The Weibull shape factor, $\beta = 2.6$ based on laboratory test. Ten valves have already survived 24 months without failure. The minimum reliability desired is 95%.

The questions:

- 1) How much longer will the valves survive (**given they have already survived for 24 months without failure**) and you want them to demonstrate 95% reliability at removal from service?
- 2) What method would you use for finding the remaining life to achieve 95% reliability for the 10 survivors who are still alive at 24 months?

The answer:

The current survivors are expected to survive for 6 more months ($24+6=30$ months) and the chance for survival is 95%. Please note: reliability + unreliability = 1 where unreliability is often called the probability of failure and for this case we have a 5% chance for failure in the next 6 months. Why is reliability important?—it sets the risk levels. If the consequences of pressure vessel failure is \$1,000,000 and the probability of failure is 5% then we have $\$Risk = pof * \$Consequence = 5\% * \$1,000,000 = \$50,000$. Don't take more risk than you can afford, it will wreck your business and get you fired. Don't take too little risk, if wasted good money. You've got to get the risk correct: Not too much risk and not too little risk—it's got to be just right, and different businesses

allow different risks. When you speak of reliability you speak about the sweet side of the coin, when you speak about unreliability, you speak about the sour side of the coin—by the way, when you know one, you also know the other.

Please note that survivors that have completed the planned, scheduled, replacement interval does not always require instant removal from service for testing—from the answer below, you'll see that a grace period can exist. It's a conditional reliability issue.

How to get the answer:

a) *The easy way to an answer-*

1. Go to [WinSMITH Weibull](#) software (you can download a [demo version](#) which will solve this problem as you will not have to supply data into the data spreadsheet which would result in some randomization of the data spreadsheet).
2. Open the **calculator icon** (top row, 6th from the left hand side).
3. Open the menu option for **life remaining** after no (zero) failures.
4. Input the known information of:
 - beta [**2.6**],
 - eta [**72 months**],
 - present age [**24 months**], and
 - probability of failure (pof = 1- reliability) [**5%**].
5. Read the results as expected remaining life usage [**6.67 months**]. Round the answer down to be conservative to get **6 months**.

b) *The hard way to an answer-*

1. Reliability at 24 months was expected to be
$$R(24) = \exp(-(t/\eta)^\beta) = \exp(-(24/72)^{2.6}) = \exp(-(0.333)^{2.6}) = \exp(-0.0573)$$
$$= 94.4144776\%$$

Whereas the valves have show no failures to compromise reliability.

2. Conditional reliability equation is

$$R(24+x)/R(24) = 95\%$$

Where (24 + x) is the current surviving age and x is the additional number of months of life to achieve a conditional reliability of 95%. This means the future reliability will be $R(24+x) = 89.6937537\%$ given the parts are alive today at time 24 months. Why use conditional reliability calculations??—it's because the valves have already survived to the current time of 24 months without failure (given an expected reliability at 24 months of 94.4144776% at starting time zero).

3. Open Excel, click on Tools, click on Options, click on Calculations, in the dialog box click on Iteration, change maximum Iterations to 10000, change maximum Change to 0.00001.

This sets-up conditions for use of the Excel tool called Goal Seek so we get an accurate answer.

4. In Excel cell **A1** input the trial value for x as

1

This is done so that Excel will have a starting guess value for iterating the correct value for x.

5. In Excel cell **A2** and write (or copy/paste the equation below) the conditional reliability equations:

$$=(\exp(-1*((24+a1)/72)^{2.6}))/\exp(-1*(24/72)^{2.6})$$

6. In Excel, click on Tools, click on Goal Seek, in the dialog box

set cell **\$a\$2** (the equation) to value **95%** by changing cell **\$a\$1** (the guess number).

7. Get the answer in cell **A1** =

6.673 months rounded down to 6 months.

8. Yes, we could have solved for time mathematically this way:

$$R(24 + x) = e^{-((24+x)/\eta)^\beta}$$

$$e^{((24+x)/\eta)^\beta} = 1/(R(24+x))$$

$$((24+x)/\eta)^\beta = \ln(1/(R(24+x)))$$

$$(24+x)/\eta = \{\ln(1/(R(24+x)))\}^{1/\beta}$$

$$24 + x = \eta \cdot \{\ln(1/(R(24+x)))\}^{1/\beta}$$

$$x = -24 + \eta \cdot \{\ln(1/(R(24+x)))\}^{1/\beta}$$

$$= -24 + 72 \cdot (\ln(1/89.6937537\%))^{1/2.6}$$

$$= -24 + 72 \cdot (\ln(1.114904839))^{0.384615}$$

$$= -24 + 72 \cdot (0.426015604)$$

$$= -24 + 30.67312352$$

$$= \mathbf{6.673} \text{ months rounded down to 6 months as shown above in step 7.}$$

Additional facts of life about relief valves:

You can only determine pressure relieve valve failure **in the dangerous direction** by periodic pressure testing. Testing lets you learn what you don't know until proven by a high pressure test. Of course, if the pressure under the valve continues to stay below the maximum allowed pop pressure, the relieved valve overpressure failure is **benign** because the valve is not demanded to pop open to relieve the high pressure.

If pressure under the relief valve exceeds the maximum allowed pop pressure the valve has failed **in the dangerous direction**. If a relief valve is called to perform its duty at high pressure and it won't open, then a benign failure can become a failure **in the dangerous direction**. Dangerous failures can become time bombs because of the unknowns.

If pressure under the valve is less than the minimum allowed pop pressure, pressure relief valves can leak because of **valve simmer** from the slow leak then the valve has failed in the safe direction. Simmering safety valves are observable failures. Simmering relief valves usually get removed from service for service/replacement to prevent leakage.

A safety valve may appear unfailed only because it has not been stressed from pressure below the valve. It may appear unfailed because it has not been tested periodically to show it's capabilities for relieving pressure safely within the allowed safe range.

Safety relief valves in very clean service, where pressures are controlled by system restrains, can have very long life, free from sticking, and blockage. Clean service occurs in service with **refrigeration pressure relief valves** as an example. When clean valves with pressures well below the control limit are tested coming back from the field for

periodic verification, a large percentage (about 95%) of relief valves will pass the outgoing standard. The valves must be tested as received from the field (not cleaned-up and not reassembled before testing). The pop open pressure data must be recorded in variable format (actual pop pressure recorded in appropriate units with comparison to the outgoing standard for acceptable/non-acceptable performance), and the pop pressures should not be recorded in attribute format (pass/fail).

Safety relief valves in dirty/sticky/gummy/high-temperature/low-temperature service can have very short life due to sticking and blockage as occurs in refineries or chemical plants and these problems are called failures. Failure problems are especially true where the maximum pressures to be sealed are very near the maximum allowed by the relief valve as the valve may chatter open and sit down in its own sticky refuse in the valve which will act like “glue” to stifle clean operation of the valve to break over and relieve pressures from damaging equipment.

In dirty/sticky/gummy pressure service the roughness of loading problems occurs with surges and dynamic loads which can contaminate relief valves from the fluids/gasses to be sealed. The roughness of pressure loads on pressure relief valves has the same type effect on safety factors as occurs with mechanical loads on materials with the resulting condition of varying safety factors on the dangerous side because of interference of [load-strength conditions](#).

Often the dirty/sticky/gummy pressure relief valves don't open inside the hi/lo limits. In fact, they simply don't open at any reasonable pressure! This failure to open and relieve pressure becomes a time bomb waiting for a call for duty, and they can't perform the intended function for which the pressure relief valve exists.

An example of the early open problems (**about 20%**), open within the normal allowed range (**about 60%**), and open in the dangerous direction (**about 20%**) are described in a normal probability plot, Figure 3, page 316 of **Trans IChemE**, Vol. 60, 1982 from the article “*Reliability Assessment Of Safety/Relief Valves*” by R. J. Aird (pages 314-318) as shown in Figure 1. Based on test valve test data I have observed, I agree with Aird's observations, unless the operation is unusually clean service.

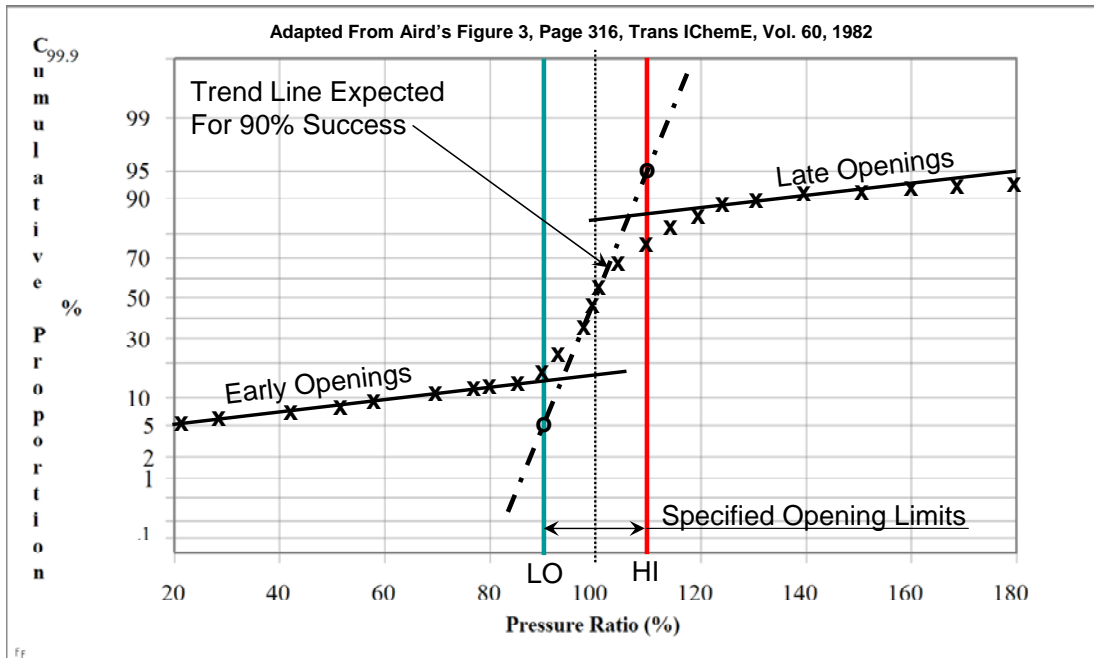


Figure 1: About 60% of Relief Valves Open Within The Allowed Range

Some times the solution to a contamination problem for relief valves is to use a rupture diaphragm between the high pressure and the safety relief valve. The rupture diaphragm and the relief valve become a function series reliability model requiring a higher relief valve reliability to achieve the expected system reliability for service.

The inferior practice of disassembling pressure relief valves removed from service, cleaning the valve and reassembling the valve before performing the pressure test will not discover the blockage from sticking/blockage. Thus a successful pressure test obtained from this practice is a false success staged for eye-wash.

Age in service to failure is important—here is a time keeping problem. A relief valve has been in service for 3 years. It is removed from service, tested as passing the min/max pop pressures. The valve is disassembled, cleaned, and placed back into service (with the presumption of being restored to zero time). At the second 3 year interval it is removed from service, tested and it fails the second pop test. The age to failure is 3 years (the age to failure IS NOT 6 years because the valve has been cleaned and restored to zero time for the second campaign). Time keeping of ages to failure is very important for making decisions about life in service.

The perception:

Suppose we have a relief valve that must pop at 300 psi and we are allowed $\pm 5\%$ for the pop range. That means the valve must open between 285 psi and 315 psi. Unfortunately, the high side of pressure relief is measured with rubber rulers which are stretched to fit a political agenda. The political agenda does not reduce the risks to the business. Allowed relief ranges should be handled without excuses and without use of rubber rulers.

Why?—the inferior logic becomes if it is OK to steal pennies from the cash register till,

then it's OK to steal nickels, and if OK to steal nickels, then it's OK---you've got the picture! Don't handle upside exceptions from an Enron perspective! Be squeaky clean and follow a rigid procedure.

If peak pressures vary and pressure relief valves relieve at variable pressures how will you know where you are:

You can have [load-strength interference](#) problems that will decrease reliability of the system. How do you get the loads?—collect the maximum daily pressures recorded on the system and make a [Gumbel upper probability plot](#) for the load. Take the pop pressures from a family of similar values and make a Weibull probability plot for the strength. Use the two probability models to find the % interference.

Relief Valve Resources:

ASME Consolidated Safety Relief Valve Code Excerpts SRV-1

ANSI/API RP 520, Part 1 Sizing and Selection, Sizing, Selection, and Installation Of Pressure-Relieving Devices in Refineries

ANSI/API RP 520, Part 2 Installation, Sizing, Selection, and Installation Of Pressure-Relieving Devices in Refineries

API RP 521, Guide for Pressure-Relieving and Depressuring Systems

ANSI/API 527, Seat Tightness of Pressure Relief Valves

ANSI/API RP 576, Inspection of Pressure-Relieving Devices

Comments:

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](#). [Return to top of page](#).

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