Risk-based inspection (RBI) methodology constitutes a fundamental point in the inspection planning in order to control and mitigate risks that involves process industry. Risk is used as priority criterion in the forecast of optimal inspections intervals. Several methods of RBI have been developed to use appropriate methodologies for applying to various industry components. American Petroleum Institute (API), as an institution has developed a standard document, as a guide to RBI, applicable to a wide range of equipments inside processes industry. This document, however, does not present a systematic understanding or simple and immediate application, that the reason why it is always welcome to industry, any initiative indicating simplified risk assessment methods for give to operators some tools, to better quantify, assess state of components and help them in the vast resources of inspection available, for reducing risk.

In this work a survey of current state of art of RBI methodology applied to Pressure Relief Devices (PRDs) in processes industry was made. It was also developed the identification of critical parameters of analysis as well as its determination. It was also made a synthesis of API RP 581, API RP 580 and an approach on the Weibull analysis and the determination of probability of failure by this method. Finally, the methodology was applied in practical cases, through application of software, which was developed based entirely on API RP 581 standard, very easy to use, quantify and determine probability of failure, and parameters that enabled determination of such probability.

1. Introduction

Since we were born all of us make risk decisions. Risk is associated to any adverse event (consequences) what can happen to everyone, so as its possibilities of occurrence (probability of failure) can be great or just little. PRD, Pressure Relief Devices, are the equipment in high-risk industrial platforms, so, optimal inspection interval is the key to minimize the risk. A calculation of risk with the RBI (risk-based inspection) API (American Petroleum Institute) involves determining the probability of failure combined with its consequence.

Failure of a PRD is, not fulfilling the function what was supposed to do, which must occur when the equipment does not perform in any way its function, or performs it badly, not comply with the objectives for which it was designed.

Defining risk as the combination of the probability of a failure during a time interval with the consequences, as follow:

\[
Risk = \text{Probability of failure} \times \text{Consequence}
\]

The probability is known as dimensionless. The consequence of failure, however, is measured in monetary values per unit of time (annual monetary losses). So the risk is almost always measured in
€/year, can also be measured in area/year, the area affected by the damage for one year. But in this work the unit of measurement used is €/year.

### 1.1 Project of the PRDS

PRDS is the devices designed to help external pressure or vacuum in a container does not exceed a predetermined value, doing that by transfer of fluid to a closed system or atmosphere.

There are main types of PRDS which are divided into three groups, such as a) Reclosing type b) Vacuum type and c) Non-reclosing type.

#### 1.1.1 Inspection programs and risk management for the PRDS

Inspection for PRDS must be done to provide protection in case of emergencies. This inspection should include necessary factors which may affect performance of valves.

They are considered following factors:

- Temperature variation, environmental and system factors
- Vibration
- Residue in the inner parts of valve
- Elements of valve subjected to tension
- Turbulence in fluid
- Sizing and configuration of discharge pipe
- Sizing and configuration of intake pipe
- Design

### 2. Analysis of Weibull model

Weibull model is an empirical expression developed by Ernest Hjalmur Wallodi Weibull, Swedish physicist, who in 1939 presented the model in planning of statistical fatigue of materials. Its usefulness, to allow:

- Represent typical initial failures (infant mortality), random failures and failures due to wear.
- Get important parameters for configuration of failures.

The probability density function of Weibull distribution, known as the Weibull function with three parameters, has the following form:

$$ f(t) = \frac{\beta}{\eta} \left(\frac{t - t_0}{\eta}\right)^{\beta-1} \cdot e^{-\left(\frac{t - t_0}{\eta}\right)^\beta} \quad (2.1) $$

Where \( e = 2.7183 \), \( \beta \), \( \eta \) and \( t_0 \) are parameters with following meanings:

- \( t_0 \) - Parameter of location, corresponds to the lowest value given by \( t \) (for example, in the case of failure modes that had a cause a wear or fatigue, failure may occur only after some time of operation).
- \( \beta \) – Shape parameter, it reflects a mechanism of degradation, indicates the shape of the curve of probability and the characteristic of failure.
η - Parameter of scale (or characteristic life), corresponds to the life characteristic value, the time interval between \( t_0 \) and \( t \) which occur 63.2% of failures, leaving therefore 36.8% of items without failure.

When we consider data modes failure of a system, we often consider that the lower limit of life \( t_0 = 0 \), and it is fairly acceptable. Accordingly, the above expression simplifies, moving to contain only two parameters, it is considered that the equipment has no operating time, back to the pristine state \( (t_0 = 0) \) for the inspection in question.

\[
F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^\beta} \tag{2.2}
\]

![Fig. 1: Cumulative probability function of Weibull with two parameters](image)

This function is called the cumulative probability function of failure, sometimes referred as unreliability.

The assumption used to determine the parameters of Weibull pattern is that the PRDS on similar services have the same probability of failure on requesting, \( P_{\text{req}} \), and the probability of leakage, \( P_l \), is also similar. Therefore, rate of failure data of industry may be used as a basis to establish initial value (or default) probability of failure for a specific device.

### 2.1 Bayesian Updating

Update for the values of Weibull parameter, \( \eta \), is made statistically based on the Bayes theorem, by calculating Bayesian updates. The Bayes theorem is a corollary of total probability theorem which allows us to calculate the following probability:

\[
Pr(A|B) = \frac{Pr(B|A) \cdot Pr(A)}{Pr(B)} \tag{2.3}
\]

Where:

\( Pr(A|B) \) are the priori probabilities of A conditioned to B.

The Bayes rule shows how to change the priori probabilities based on new evidence in order to obtain a posteriori probability.
3. Software for applying to RBI for PRDs

In accordance with regulatory requirements for testing and inspections this software aims to provide a basis for calculation of specific Weibull parameters for PRDS, it is not, however, a software for a complete API RBI evaluation covering all the API RP 581 standard for this equipment.

The algorithm of software, is represented in the diagram of Fig. 2

![Diagram of calculation in the software](image)

The software has a main menu (Figure 3) where user makes a choice to what failure mode analysis will proceed, whether it is failed to open (FAIL) analysis or Leak (LEAKAGE) analysis.

![Software main menu](image)

This menu gives the user the possibility to choose which of the failure modes will make study, it can select between LEAKAGE or FAIL mode.

To analyze the parameters and probability of failure for the failure mode chosen, it will appear one of the following window:
In the first panel of these two windows recognizes of entity to which this application was developed is made, and describes its usefulness and purpose. In the vertical left, user enters values previously established by simple analysis of tables and conditions what can be seen in the API 581, and values arising from the experience of inspector. These values are, therefore, the inspection interval, the parameters of Weibull default (or initial, can be found in the API 581), adjustment factor, maximum allowed working pressure (MAWP), excess pressure, adjustment factor environmental factors confidence factor (CF), test duration or time of operation of device without inspection and the number of inspections or tests. In this panel we can see a pop-up menu that allows choosing which standard of review that device has experienced, this is done using the table of effective inspection, table 7.7, API 581. Finally, this panel there is a value that is given through internal calculations of Life program and the last feature adjustment factor of pressure.

Then we see the right three Pusshbutton, estimate, close and save the results as. In the chart area, gives the probability of failure analysis, and device in question, the probability of failure that will be used to determine the risk and so in order to make the analysis of RBI, obeying standards API RP 580 and API RP 581.

To analyze the parameters and probability of failure for the mode LEAKAGE you'll see a window with the configuration window shown in Figure 3a.

4. Application to cases of safety valves studied

It is necessary to ratify and consolidate the study of risk-based inspection of PRDS made so far by an application in practical cases, far below, will be made the determination of Weibull parameters for evaluating the probability of failure caused by any failure to open or how or by leakage.

4.1 Data from a processing unit in a refinery

Initially a survey was done only with data from the TR 69 valves (49 and safety relief and relief of 20) was examined in stopping a refining unit in 1998 after a successful operation during 3 years. These data are presented in Table 1.
Analysis of these data shows what can be summarized in the following table:

<table>
<thead>
<tr>
<th>Situation of PRDs</th>
<th>Safety and relief valve</th>
<th>Relief valve</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opened in the tolerance range and kept the tightness</td>
<td>Qty. 19</td>
<td>% 39</td>
<td>Qty. 4</td>
</tr>
<tr>
<td>Opened in the tolerance range and didn't keep the tightness</td>
<td>Qty. 15</td>
<td>% 31</td>
<td>Qty. 3</td>
</tr>
<tr>
<td>Opened 20% above set pressure</td>
<td>Qty. 4</td>
<td>% 8</td>
<td>Qty. 2</td>
</tr>
<tr>
<td>Opened 20% to 40% above set pressure</td>
<td>Qty. 0</td>
<td>% 0</td>
<td>Qty. 8</td>
</tr>
<tr>
<td>Opened 40% above set pressure</td>
<td>Qty. 3</td>
<td>% 6</td>
<td>Qty. 2</td>
</tr>
<tr>
<td>Opened 95% down set pressure</td>
<td>Qty. 2</td>
<td>% 4</td>
<td>Qty. 1</td>
</tr>
<tr>
<td>Had leakage before open</td>
<td>Qty. 6</td>
<td>% 12</td>
<td>Qty. 0</td>
</tr>
</tbody>
</table>

Table 1: Results of inspection and TR after stopping at a refinery in 1998

At the time were not identified because it is not considered, the causes that led to poor results in the TR of these valves.

Then, in 2000 and 2004, were made during and after they stop working for a period of 2 and 4 years respectively, a more detailed survey of the results of the TR safety and relief valves, in order to determine the availability valves and the optimal inspection intervals, as had the aim of adopting a range of 5 years for such unit.

After this analysis it was decided, as a general rule, establish inspection intervals for 2 ½ years for the valves that failed. For the other valves was recommended to monitor the period of inspection of the equipment protected.

4.3 Documentation required at prior

Data collection is essential at prior to proceeding API RBI analysis, as well as standard provides the inspector must be able to make the compilation of this information means that through the API RP 580 or API RP 581 can meet all the conditions that facilitate the fast and efficient access to them and make the evaluation process more feasible.

4.4 Results applying software

Calculations in that software primarily, aimed determining the parameters of Weibull and ultimately the failure probability or FAIL LEAKAGE, are based on the procedure for calculating of API RP 581 and give us the probability of failure for a range specified inspection.

Consider one of the valves in the refinery case cited above. As we exposed the same PRDS underwent three TRs at different times, the first in 1998, then, in 2000 and 2004, it is clear that many valves were replaced and some added ways to improve safety, however, at least most of them still continued their normal operation.

We will identify these valves by the letters X and Y, in fact, the valves are considered, a relief valve and other safety and relief valve, all of them conventional.

4.4.1 Evaluation for X valve (safety and relief)
The following input data were the result of field research by a surveyor by the codes tabulated in API RP 581.

<table>
<thead>
<tr>
<th>Confidence factor (CF&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>Duration (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF&lt;sub&gt;leak&lt;/sub&gt;</td>
<td>CF&lt;sub&gt;noleak&lt;/sub&gt;</td>
</tr>
<tr>
<td>0.50</td>
<td>2</td>
</tr>
<tr>
<td>0.50</td>
<td>4</td>
</tr>
<tr>
<td>0.70</td>
<td>5</td>
</tr>
</tbody>
</table>

*Table 2: History valve study by consulting the API RP 581*

So here we are in condition to make the calculations using the software for this valve just seeing API RP 581.

**Results:**

<table>
<thead>
<tr>
<th>t&lt;sub&gt;insp&lt;/sub&gt; [Years]</th>
<th>β [Years]</th>
<th>η&lt;sub&gt;def&lt;/sub&gt; [Years]</th>
<th>F&lt;sub&gt;s&lt;/sub&gt;</th>
<th>F&lt;sub&gt;env&lt;/sub&gt;</th>
<th>η&lt;sub&gt;mod&lt;/sub&gt; [Years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.80</td>
<td>23.90</td>
<td>1.25</td>
<td>0.50</td>
<td>14.94</td>
</tr>
</tbody>
</table>

*Table 3: Values introduced to the program and changed life calculated by him for LEAKAGE*

<table>
<thead>
<tr>
<th>η&lt;sub&gt;upd&lt;/sub&gt; [Years]</th>
<th>t [Years]</th>
<th>P&lt;sub&gt;t&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.03</td>
<td>11.02</td>
<td>5.45</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>0.04</td>
<td>0.28</td>
<td>0.97</td>
</tr>
</tbody>
</table>

*Table 4: Calculated by program to determine the probability of LEAKAGE*

These results only confirm advantages of this methodology for analysis of risk-based inspection through probability density function of Weibull. It was expected that the characteristic life to degrade as the years pass and the valve was failing, in the case, leaks. Note that for the first two inspections there was no leakage, which justifies the fact that the life of the component does not decrease significantly. However in the third inspection, as shown in Table 2, there have been an increase in operating time without inspection, which justifies the fact that the life of the PRD significantly decrease from 11 to 5 years. See the figure below the trend curve of probability of leakage.

![Fig. 5: Evolution of probability of leakage](image-url)

The graph in Figure 5, although few data, gives us a sense of how would be the evolution of probability of failure, for this valve as time goes on, making it necessary shorten on the inspection intervals.
4.4.2 Evaluation for the Y valve (relief)

For this case it has more data, it will improve perceptions of evolution for probability of failure over time and will see how it is easier to interpret data and analyze them if they are available in detail. The following input data were the result of field research by an inspector through codes tabulated in API RP 581.

<table>
<thead>
<tr>
<th>Confidence factor (CF&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>CF&lt;sub&gt;pass&lt;/sub&gt;</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
<th>0,50</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF&lt;sub&gt;fail&lt;/sub&gt;</td>
<td></td>
<td>0,70</td>
<td>0,70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (Years)</td>
<td>T&lt;sub&gt;dur,i&lt;/sub&gt;</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5: Historical data of studied through API RBI 581

Results:

<table>
<thead>
<tr>
<th>t&lt;sub&gt;insp&lt;/sub&gt; [Years]</th>
<th>β</th>
<th>η&lt;sub&gt;def&lt;/sub&gt; [Years]</th>
<th>F&lt;sub&gt;c&lt;/sub&gt;</th>
<th>MAWP [kPa]</th>
<th>P&lt;sub&gt;0&lt;/sub&gt; [kPa]</th>
<th>F&lt;sub&gt;op&lt;/sub&gt;</th>
<th>F&lt;sub&gt;env&lt;/sub&gt;</th>
<th>η&lt;sub&gt;mod&lt;/sub&gt; [Years]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>1,80</td>
<td>23,90</td>
<td>1,25</td>
<td>1500</td>
<td>6000</td>
<td>0,80</td>
<td>0,50</td>
</tr>
</tbody>
</table>

Table 6: Values introduced to the program and changed life calculated by him for FAIL

<table>
<thead>
<tr>
<th>η&lt;sub&gt;upd&lt;/sub&gt; [Years]</th>
<th>t [Years]</th>
<th>P&lt;sub&gt;fail&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,80</td>
<td>3</td>
<td>0,58</td>
</tr>
<tr>
<td>6,40</td>
<td>6</td>
<td>0,85</td>
</tr>
<tr>
<td>6,20</td>
<td>9</td>
<td>0,97</td>
</tr>
<tr>
<td>5,90</td>
<td>12</td>
<td>0,99</td>
</tr>
<tr>
<td>5,80</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>2,30</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>4,40</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>4,20</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>4,00</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>2,10</td>
<td>25</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 7: Values calculated by the program to determine the probability of FAIL

![Fig. 6: Evolution of probability of failure to open](image)

This latter case is easier for understand because there is more data to study than the first case. Note, in this case, the probability that the equipment would fail grow fastest than the first case, this can be explained by the fact that there are many factors that contribute PRD does not open when prompted, and that this failure mode includes other failures to open as late opening of the device, valve stuck open or partially are failures that occur frequently.

5. Conclusions

In a RBI API assessment, it is recommended to review the attached tables, API RP 581. They are simple perception as to the quantitative evaluation of the software presented in this paper is
concerned to solve it in order to facilitate the process of calculation and which conducts the evaluation. We considered details of the safety valves and relief systems pressures, made the approach practical recommendations and analysis, introduction to risk-based inspection. The software is simple to apply, once collected the information required by him, can be used on any operating system, as it was made an executable to run it on any computer. However it should not be construed as a software evaluation RBI API, but as a useful aid.

Studied cases were, here generalize the application of software and leads to the perception of the beginning of an RBI API evaluation. More cases could be studied, but the lack of data and its difficult to obtain it conditioned the consolidation of this work. But it should be noted that here was satisfied the requirements for the originally intended, namely the determination of Weibull parameters for later analysis of API RBI.

The main difficulty in this study was to evaluate available data, which was insufficient and sometimes inadequate for determining the probability of failure and to proceed RBI API evaluation. It is hoped that with this work a collection of appropriate information in accordance with API RP 580 and API RP 581 can be make to proceed a RBI API.

Evaluation of API RBI becomes complete by determining the risk that each component where PRD are subjected. That is why in future we can continue quantitative determination of consequences of failure and the risk associated with these consequences. Can be developed further, a software more complete analysis of the API RBI for PRDS.

In future it can be make too an adequacy, simplification and determination, with the help of some software, the consequences of failure of PRDS for the two failure modes considered.

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