Project: Lid and Leak-Down Tester Design for Low Level Waste Container

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1. Background

As a part of the clean-up effort taking place at Hanford National Laboratory, Bechtel National Inc. is currently designing and building a massive waste treatment plant to remove low activity and high level waste currently being stored in possibly deteriorating underground storage tanks. This waste treatment plant requires the design of a lid for new low-activity waste containers and leak-rate tester to test the seal between the lid and container. The project will be conducted as part of the Mechanical Engineering Capstone Design class at the University of Idaho. Dr. Steven Beyerlein, Dr. Karl Rink, and graduate student Andrew Dubuisson will assist the team with leak rate calculations, fabrication, and design problems the team may encounter.

The team will provide Bechtel National, Inc. with a detailed project schedule, complete economic analysis of the project, the preferred lid design with design alternatives, a leak rate tester with test parameters and setup, and a final report and presentation. All deliverables will be provided to Bechtel National Inc. by April 30, 2003.

2. Problem Definition

Bechtel National Inc. currently uses welding to seal the lids of their low-activity waste containers, and wishes to replace this process because of its high cost of operation and maintenance as well as length of time to complete. A new method of sealing is required as well as a design apparatus to test the leak rate of the lid design. The current requirements for acceptable leak rates are .003 cubic centimeters per second.

Figure 1: Low Activity Waste Container

The new lid design will be incorporated in Bechtel’s waste-to-glass process. This process involves pouring liquid glass into the stainless steel low-activity waste containers. Sealing will occur before the container has a chance to cool completely. The new lid must therefore be able to survive a temperature of up to 500 degrees Fahrenheit and be made of stainless steel. To prevent any contaminated dust from collecting in the lid of the container, the lid should also have minimal crevices when it is secured.
The containers will be transported from the waste processing center to the storage site. The time from sealing until the containers reach the storage site may be as long as a week. The lid must hold its seal for at least a week, survive the shipping, and survive all types of weather. In order to prevent anything from catching on the lid during shipping, the lid should not protrude above the top of the container.

The leak rate tester will measure the leak rate of the lid design to ensure that it meets the requirements. The leak rate tester must measure leak rate of up to .001 cubic centimeters per second, a parameter set by Bechtel National Inc. The leak rate tester should also be easily adaptable to enable the testing of multiple lid designs.

3. Lid Design Concepts Considered

3.1 Press Fit Lid

A simple press fit lid was one of the first lid alternatives discussed. The lid is held in place and the seal is created by interference between the lid and container top. An inner flange was incorporated to allow the lid to always be flush after it is pressed into place. The benefit of a press fit design is the simplicity in manufacturing. There are no complicated contours that have to be machined. The top of the lid once installed is flush and has only one small crevice where lid meets the top of the container.

A factor that we will be addressing is the press force required to install such a large lid. Bechtel originally discussed using a press fit lid. There was concern that the press force required to fit the lid would in the process damage the container. In order for the press fit to be a viable solution a stress analysis of the container must be performed. An approximate press force must be determined and used in the analysis.
3.2 Threaded Lid

The second design alternative that we discussed was a threaded lid design. In this design, the lid has outside threads and the container has inside threads. The leak path could possibly be more complex with threads and therefore result in a more complex leak rate analysis. Further, the use of a metal o-ring or a metal gasket would increase the quality of the seal. The lid once in place would be extremely rigid and would have a likelihood of coming off even if the entire container were to be tipped over. The difficulty with a threaded design is the installation of the lid. In order to have proper installation the lid would need to be aligned very precisely. Misalignment of the lid could cause the threads to be stripped out making the lid impossible to properly install. Another area of concern would be the actuating force required to install the lid and the method of installation. The surface would have to be machined in order to allow for an apparatus to screw the lid in place. The incorporation of such an installation system may introduce a greater cost than is currently associated with the welded lid design. The final concern is with overspill of the vitrified glass. This problem is associated with other lid designs however is not extremely critical because of the simple contours of the lid designs. If overspill occurs and the threads are partially filled with glass, it would be more difficult to remove the glass from the threads.

3.3 Twist and Lock Lid

The third design alternative was a twist and lock lid. The lid rests on an inner flange machined into the top of the container. Tabs at the bottom of the lid slide through slots in the bottom flange of the lid. The lid would then be turned clockwise and the tabs would slide on the underside of the bottom flange. The tabs on the bottom of the lid will be tapered and will allow the lid to slowly engage bringing the lid flush and compressing an o-ring or c-ring seated underneath the lid.

Figure 3: Twist and Lock Lid and Adaptor
3.4 Contoured Lid

The fourth lid design is a contoured lid. This lid incorporates a metal o-ring and a lip similar to a paint can. The lid is initially held in place by a slight interference press fit. As the lid and container cool, returning from thermal expansion, a shrink fit is formed. A metal o-ring seated on the inner face of the lip is compressed as the lid and container contracts. This lid design focuses on the thermal properties of the lid in order to increase the quality of the seal.

4. Lid Thermal Effects

In each lid design an analysis of thermal properties will be incorporated. The container will be subjected to higher temperatures than the lid roughly 1200 to 1500 degrees Fahrenheit. The lid will be installed at temperatures in the range of 300 to 500 degrees Fahrenheit. The container will then be allowed to cool as it is transported and placed in permanent storage. It is anticipated that we will be able to use the temperature change to improve the seal. The difficulty will be allowing the design to be flexible. The temperature the container and lid are exposed to will not be exact and will be within a certain range. The tolerances of the lid and container will have to be chosen based on this knowledge. The incorporation of thermal properties will only be useful if it can be designed to function properly within the range of temperatures the lid and container will be exposed to.

5. Final Lid Decision

Each lid design was compared in five categories. These categories were chosen according to the design goals. Cost and sealing ability were the most important factors in the lid designs. Accordingly, these categories played more heavily in our decision. The decision matrix below shows the results of the analysis. The numbers shown are based on how well we thought the lid would perform. Note it was assumed that all lids would have a leak rate of less than .003 cm^3/sec.
Table 1: Lid Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Cost (x2)</th>
<th>Easy of Application</th>
<th>Sealing Ability (x2)</th>
<th>Crevices</th>
<th>Manufacturability</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press Fit</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Threaded</td>
<td>16</td>
<td>8</td>
<td>12</td>
<td>4</td>
<td>7</td>
<td>47</td>
</tr>
<tr>
<td>Twist &amp; Lock</td>
<td>10</td>
<td>9</td>
<td>16</td>
<td>7</td>
<td>4</td>
<td>46</td>
</tr>
<tr>
<td>Contoured</td>
<td>12</td>
<td>10</td>
<td>20</td>
<td>7</td>
<td>6</td>
<td>55</td>
</tr>
</tbody>
</table>

6. Lid Concepts Chosen

In selecting preliminary lid designs we focused on lids that would be easily manufactured in our shop and installed. The press fit lid design was the top of our preliminary list of designs. The simplicity of the design masks the assumed quality of the seal that can be created. The application of such a lid may or may not be ideal. The pros however outweigh the cons and a deeper analysis of the feasibility of using a press fit will be addressed. The threaded lid design was ruled out because of the complexities associated with alignment, installation, and overspill. In analyzing this particular lid design we found there were too many modes of failure. The twist and lock lid design was also ruled out later in the design phase. There are two main reasons the twist and lock lid was eliminated as a design possibility. First the time and difficulty manufacturing this particular design may outweigh its usability. Second the design requires two slots machined into the fixed diameter of 15.5”. We made a decision to stay away from designs that compromised the fixed constraints in any way. A decision was made to continue the manufacturing and testing of the contoured lid. We will look into modifying the design slightly to ensure the quality of the seal. We will not be limited to the two main lid design ideas chosen alone. We will continue to research and discuss improved lid designs.

A final decision was made to look further into the use of thermal properties of differing materials to improve the seal of the lid. The extreme temperature gradient can be used to our advantage. We will look at multiple ways to incorporate and verify thermal expansion and contraction into our lid design. In addition we will look at ways the lid designs can be affected by large temperature gradients and modes of failure that may be produced as a result.

7. Leak Rate Test Concepts Considered

There are two areas in which concepts were considered, first methods of leak testing and second lid designs. A team brainstorm was conducted in each case to come up with a list of plausible ideas. The design concepts were iterated simultaneously. Mass balance, pressure gradient, and radioisotope leak detector were the three main areas of leak rate
detection that were considered. Four lid design concepts were selected, press fit, twist and lock, threaded, and contoured.

- The first method of leak rate detection discussed was the incorporation of a mass balance. The general idea behind this concept is to determine the mass decay of a substance either entering or leaving a container. Data is taken over a defined time period and a mass flow rate can then be approximated. An approximate leak rate can then be generated from the mass flow data. A helium mass spectrometer is a good application of this theory and is widely used in applications where accurate leak rates need to be determined.

- The second method of leak rate detection is the use of a pressure gradient. In this application the pressure inside an apparatus is either increased or decreased. A change in pressure is then measured over time. A plot of pressure verses time is created. The relationship will be a non-linear exponential decay. The data from tests can then be compared with experimental data and an average leak rate can be determined.

- The third method of leak rate detection is the use of a radioisotope leak detector. Dr Karl Rink is currently using this device in his leak rate research. A component that is to be tested is placed in the fixture. The component is then bombarded with a radioactive isotope. The amount of isotope contained inside the component is then measured and an extremely accurate leak rate can then be determined.

It is important to note that there is much variability in leak rate detection. You may be dealing with one gross leak path or many small leak paths. A leak may begin immediately or take time to develop. In general an exact leak rate is difficult to determine. The leak rates are related closely to pressure. The higher the pressure difference the greater the potential of a large leak rate. The actual leak rate will also depend on the quality of the seal. The leak rate will also decrease as a pressure difference reaches equilibrium pressure. Issues associated with relating variable leak rates to one set leak rate will have to be considered. In general the maximum allowable leak rate of 0.003 cm³/s will be set as the constraint.

In the analysis of leaks rates we will continue to work closely with Dr. Karl Rink. Dr. Rink is engaged in research dealing with leak rates at the University of Idaho. His expertise in the area of leak rates has influenced the concepts considered. Dr Rink will continue to provide direction and research information through the remainder of the project.

8. Leak Rate Test Concept Chosen

In determining leak rates we have chosen to manufacture a leak rate test apparatus out of aluminum that will use a pressure gradient. This decision comes from preliminary testing which indicates the best way for us to test and collect multiple sets of data efficiently and safely is through the use of a pressure gradient. The apparatus will have an interchangeable lid design. A 1 to 4 scale model of each lid will be manufactured and tested using this apparatus. The apparatus will determine a pressure gradient over a period of time
for each lid design. Multiple tests will be run on each lid design. The data collected will then be used to analyze the design quality related only to the leak rate of each lid. In addition once the final lid design is chosen a 1 to 10 scale prototype will be manufactured. This prototype lid will be tested in the Radioisotope Leak Rate Detector. This will allow for a more accurate leak rate approximation. It will also help us to verify test results from our pressure gradient apparatus.

The lid test apparatus consists of three major parts; the base, lid adaptors, and vacuum system. The base of the tester stands 10 inches tall, and is made up of a base plate and top flange welded to the bottom and top of a 9 inch tall, 6 inch outside diameter aluminum tube. The various lid designs can be tested under identical procedures through the use of lid adaptors. The lid adaptors provide a way of testing multiple lids using the same base apparatus. Each lid design has its own lid adaptor to simulate the interaction between the full size lid and the Low Activity Waste Container. A gasket is placed between the apparatus base and lid adaptor and is securely attached using eight bolts and nuts as seen in figure 5. Two threaded holes on the side of the tester base section accommodate a 0-50 psia pressure transducer and air venturi and needle valve assembly.

![Figure 5: Test Apparatus (Exploded View)](image)

To simulate the internal pressure conditions of the full size lid and container, after the container has been filled with the vitrified glass and sealed with the lid, the internal pressure will be dropped between 5 and 10 psia using a vacuum venturi, powered by blowing 30-70 psig shop air. When the desired vacuum is reached the needle valve is closed, and the venturi is disconnected from the shop air.

The internal pressure is measured with a 0-50 psia pressure transducer powered by a constant voltage power supply. The change in pressure is displayed in terms of voltage changes on a five digit digital multimeter. A pressure reading will be taken every five minutes and recorded in an Excel file. Eventually the pressure transducer will be hooked up to a data-acquisition system to take real-time data allowing for a more accurate representation of the pressure gradient decay curve.
The collected pressure data will be plugged into a math program to calculate the leak rate. To solve for the leak rate, it must first be guessed to solve for the area of the leak. Data points are generated and compared to the collected points, if the points do not match up, then the leak rate is adjusted appropriately and new points are calculated. The process continues until the calculated data points match the collected points.

9. Future Work

The main area of project work will be continuing to design and manufacture test lids. At present we have two lid designs finalized the press fit lid and the contoured lid. The press fit lid has also been machined. It is anticipated that the contoured lid will be manufactured before Christmas break. Alternative lid designs will be researched and discussed. It is anticipated that we will design and build four to five lid designs. The lid designs will be completed by the end of January. The lids will then be machined by the middle of February.

The second area of project work will be the test fixture. At present the fixture is constructed and being tested for leaks out of fixture ports and lid gasket. The calibration data for the test fixture will be completed before the end of January. Leak rate testing will then begin on the lids previously manufactured. As lids are completed tests will be run and data collected. As the fixture is calibrated a method of relating pressure decay to leak rates will be generalized and used to approximate leak rates in different lid designs.

When the recommended lid design is determined a stainless steel version of the lid design will be machined and tested. A smaller scale prototype will also be built to be used in a radioisotope leak rate detector.

Table 2: Spring Semester Time-Line

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
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</thead>
<tbody>
<tr>
<td>Manufacture Remaining Lids</td>
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<tr>
<td>Perform Leak Testing on Lid Designs</td>
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<tr>
<td>Analyze Leak Testing Data</td>
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<td></td>
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<tr>
<td>Perform Stress Analysis on Press Fit Lid</td>
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<td></td>
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<tr>
<td>Design Full Size Leak Testing Apparatus</td>
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<tr>
<td>Manufacture Top Lid in Stainless Steel</td>
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<td></td>
<td></td>
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<tr>
<td>Test Stainless Steel Lid</td>
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