MATERIALS TO RESIST THE ABRASION OF PNEUMATICALLY TRANSPORTED PROCESSED REFUSE

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ABSTRACT

This paper describes the preliminary evaluation of the effectiveness of some materials used to combat the erosion by processed refuse in pneumatic transport pipes. These transport pipes are part of a prototype operation for processing solid waste as a supplementary fuel for electric utility boilers and for the recovery of recyclable non-combustible materials.

INTRODUCTION

A full scale test program, called the Energy Recovery Project, had been conducted by the City of St. Louis, Missouri and the Union Electric Company to determine the feasibility of burning processed household refuse, along with pulverized coal, in an electric utility boiler. The program had been operated from April, 1972, through November, 1975, with intermittent shutdowns for equipment problems, construction work, maintenance work and labor strikes. A total of 48,972 tons (44,457 t) of processed refuse were burned in the boilers during this period. The operation entailed the collection, milling, and air classifying of raw municipal solid waste by the city with the remaining combustible fraction being transported pneumatically by Union Electric to a 140 MW unit boiler.

Operation of the prototype system during the first year was satisfactory, except for problems with the mechanical equipment that handled the milled refuse. Throughout this period, only magnetic metals were removed from the refuse before firing in the boiler. Solid, nonmagnetic pieces frequently caused the jamming of the air-lock feeders that supplied the material to the pneumatic transport system. Crushed glass and other abrasive materials in the solid waste caused excessive wear in the pipe bends of the pneumatic system. The quantity of combustible and noncombustible matter removed with the boiler bottom ash was excessive.

The problems became evident soon after the initial operation of the system. An air classifier was purchased and installed in late 1973 to remove glass, metals, and other unburnable objects. The classifier successfully removed the larger material that caused feeder jamming, but the remaining small particles of glass continued to erode the recently replaced pipe bends at the same rate as before the installation of the classifier. A program was initiated to find materials for use in the pneumatic pipelines to resist the abrasion of the glass that was still contained in the refuse after classification. The results of this program are described in the following sections of this paper.

MATERIALS FOR RESISTING SOLID WASTE ABRASION

As mentioned previously, the crushed glass and other abrasive materials contained with the processed refuse severely eroded the carbon steel pipe bends of the pneumatic pipeline at the supple-
mentary fuel receiving station. This problem became evident several weeks after the initial operation of the prototype system. It was decided that a program should be carried out to determine if any of the available wear-resistant materials on the market could be used to eliminate the erosion caused by the abrasive materials in the refuse. Also, it was hoped that the air classifier would remove this abrasive material, thus eliminating the largest maintenance item for U.E. personnel at the Mermec Plant. After the air classifier became operational in November, 1973, it was quite apparent that the abrasive material that was causing the damage had not been completely removed from the refuse. The new pipe bends that had been installed while the air classifier was being constructed were having holes worn in them at the same rate as that prior to the operation of the air classifier. Examination of the heavy rejects from the classifier showed that large pieces of glass, about 1/8 in. diameter and greater, had been removed from the processed solid waste. However, inspection of the milled refuse delivered to the power plant revealed that fine grains of glass, 1/16 in. and smaller, and other abrasive substances were still part of the material that was being blown through the pipelines.

Based on the existing technology, it was assumed that these fine grains of glass and abrasive materials could not be economically removed from the solid waste. Hence, the program for finding a wear-resistant material was stepped up. The results of this program are shown in Table 1. Many different types of materials were experimented with, in different locations and in different configurations. They included alloy steels, ceramics, hard-facing welding electrodes, epoxy bonded substances, refractories, and rubber pads. These materials were applied to the existing pipe bends, installed in replaceable wear-back elbows, and attached as flat plates at other points of severe wear.

The following basic assumptions were made in the evaluation of these materials:

1. By comparing all materials on the basis of the amount of refuse that was exposed to that material, it was assumed that all refuse traveling through the pipeline had contacted the wear-resistant material.
2. It was assumed that all locations have set up the same type of wearing condition and that particle velocity was similar at each location. In reality, these assumptions are incorrect, because of the different shapes and configurations of elbows, plates, pipes, and boxes.
3. It was assumed that there was no difference in the abrasiveness of classified or unclassified refuse.
4. Where there were a number of places that a type of material was tried, the location chosen for test purposes was the one that was felt would give the material the severest service.

Naturally, the materials that had no holes worn in them by the milled refuse were the ones that are of interest to prospective handlers of processed solid waste. The remainder of this paper will be devoted to a discussion of those substances.

Without being too repetitious, it should be noted that a plain carbon steel pipe bend, Item 1, Table 1, 8 in. (203 mm) Schedule 40 pipe size with a 0.322 in. (8.18 mm) wall thickness, only lasted for 13 service days, with 16 hours per day of use. About 179 tons of processed refuse were conveyed through the pipe bend before a hole was worn through it. Since the entire pneumatic pipeline originally contained these pipe bends, as illustrated in Fig. 1, these pipe bends can be used as a basis for comparison of the wear-resistant materials.

**CERAM CORE PIPE BEND**

The most promising device that can be used as original equipment or as a maintenance replacement is the Ceram Core pipe bend, Item 21, Table 1. Ceram Core is a glass fiber reinforced epoxy resin pipe bend, with an abrasion resistant liner composed of small, spherical particles of high alumina ceramic, held in a matrix of epoxy. Specially curved ceramic tiles cover the areas that receive the most exposure to the abrasive substances. Manufactured by A. O. Smith Inland, Inc., this pipe bend, shown in Fig. 2, can be easily handled and installed by two men without the aid of any lifting equipment. For the test installation, this item was attached to the original straight steel pipe with couplings made by Dresser Industries, Inc. Through this pipe bend were conveyed 5731 tons (5203 t) of refuse, with only a loss of about 1/16 in. (1.59 mm) of material from small areas on the 3/8 in. (9.53 mm) thick ceramic tiles. No other wear could be found throughout the pipe bend.
TABLE 1: EVALUATION OF WEAR RESISTANT MATERIALS AND ELBOW REPAIR DEVICES

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>SIZE</th>
<th>MANUFACTURER</th>
<th>SUPPLIER</th>
<th>LOCATION USED</th>
<th>BEGINNING SERVICE DATE</th>
<th>DATE/1ST HOLE IN MATERIAL</th>
<th>DAYS/SERVICE BEFORE 1ST HOLE</th>
<th>NO./PLACES IN SERVICE</th>
<th>REDUCTION OF THICKNESS IN. &amp; %</th>
<th>TONS* OF REFUSE EXPOSED TO MAT'L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carbon steel pipe bend</td>
<td>8&quot; Sch. 40-.322&quot; wall thickness</td>
<td>Rader Pneumatics, Inc. Portland, Oregon</td>
<td>Rader Pneumatics, Inc. Portland, Oregon</td>
<td>8&quot; pipeline</td>
<td>4-6-72</td>
<td>5-20-72</td>
<td>13</td>
<td>47</td>
<td>.22&quot;-100%</td>
<td>178.9</td>
</tr>
<tr>
<td>2</td>
<td>Carbon steel scrap pipe patch applied to pipe bend</td>
<td>.365&quot; thick</td>
<td>Unknown</td>
<td>Maramec Plant</td>
<td>8&quot; pipeline</td>
<td>8-14-72</td>
<td>8-29-72</td>
<td>11</td>
<td>10</td>
<td>.365&quot;-100%</td>
<td>370.9</td>
</tr>
<tr>
<td>3</td>
<td>Scrap laminated rubber and duck coal conveyor belt strips strapped to pipe bend</td>
<td>3/4&quot;-1/4&quot; thick</td>
<td>Goodyear Tire &amp; Rubber Co. Akron, Ohio</td>
<td>Union Electric Co. Meramec Plant-St. Louis, Mo.</td>
<td>8&quot; pipeline</td>
<td>6-20-72</td>
<td>6-27-72</td>
<td>4</td>
<td>46</td>
<td>3/4&quot;-100%</td>
<td>92.9</td>
</tr>
<tr>
<td>4</td>
<td>Armakrit rubber pad applied to pipe bend</td>
<td>3/4&quot; x 18&quot; x 10&quot;</td>
<td>Goodyear Tire &amp; Rubber Co. Akron, Ohio</td>
<td>Oberjuerge Rubber Co. St. Louis, Mo.</td>
<td>12&quot; pipeline 2nd pipe bend</td>
<td>9-1-72</td>
<td>10-3-72</td>
<td>14</td>
<td>1</td>
<td>3/4&quot;-100%</td>
<td>1496.0</td>
</tr>
<tr>
<td>5</td>
<td>Rubber pipe reinforced with steel wire, used as elbow</td>
<td>8&quot; pipe size x 3/8&quot; thick</td>
<td>Unknown</td>
<td>Oberjuerge Rubber Co. St. Louis, Mo.</td>
<td>8&quot; pipe bend X3P</td>
<td>9-20-72</td>
<td>10-5-72</td>
<td>3</td>
<td>1</td>
<td>3&quot;-100%</td>
<td>123.4</td>
</tr>
<tr>
<td>6</td>
<td>Devcon WR 2 epoxy and Gr. 7 Flint abrasive applied to pipe bend</td>
<td>Troweled from 3/8&quot;-1&quot; thick</td>
<td>Devcon Corp. Danvers, Mass.</td>
<td>Midwest Tool &amp; Supply Co. St. Louis, Mo.</td>
<td>8&quot; pipe bend X18</td>
<td>7-20-72</td>
<td>8-15-72</td>
<td>11</td>
<td>3</td>
<td>3/4&quot;-1&quot; 100%</td>
<td>276.7</td>
</tr>
<tr>
<td>7</td>
<td>Pecora Furnace Cement applied to pipe bend</td>
<td>Troweled from 3/4&quot;-1&quot; thick</td>
<td>Pecora Corp. Harleysville, Penn.</td>
<td>Pecora Corp. Harleysville, Penn.</td>
<td>8&quot; pipe bend X18</td>
<td>7-31-72</td>
<td>8-11-72</td>
<td>5</td>
<td>2</td>
<td>3/4&quot;-1&quot; 100%</td>
<td>110.3</td>
</tr>
<tr>
<td>9</td>
<td>Carbon steel box left empty, to be filled with refuse, attached to pipe bend</td>
<td>8&quot; high, 11 gauge steel</td>
<td>Meramec Plant</td>
<td>Meramec Plant</td>
<td>8&quot; pipe bend XIA-XAA; X18, X1B</td>
<td>1-10-73</td>
<td>3-6-73</td>
<td>32</td>
<td>8</td>
<td>Not Applicable</td>
<td>577.1</td>
</tr>
<tr>
<td>10</td>
<td>Expanded metal in carbon steel box, attached to pipe bend</td>
<td>8&quot; high</td>
<td>Filler &amp; Box - Meramec Plant</td>
<td>Meramec Plant</td>
<td>8&quot; pipe bend X18</td>
<td>1-13-73</td>
<td>3-6-73</td>
<td>24</td>
<td>1</td>
<td>Not Applicable</td>
<td>457.8</td>
</tr>
<tr>
<td>11</td>
<td>Steel floor grating in carbon steel box, attached to pipe bend</td>
<td>8&quot; high</td>
<td>Filler &amp; Box - Meramec Plant</td>
<td>Meramec Plant</td>
<td>8&quot; pipe bend X18</td>
<td>1-23-73</td>
<td>3-6-73</td>
<td>24</td>
<td>1</td>
<td>Not Applicable</td>
<td>457.0</td>
</tr>
</tbody>
</table>

* Before first time plugged
** Pipe bend plugged with refuse
*** Box plugged with refuse
**** Use XI pipeline because of lower blower speed
***** Patch had no holes, pipe bend too badly eroded to support patch

NOTE: The operation of the Energy Recovery Project was terminated on November 30, 1975.
<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>SIZE *</th>
<th>MATERIAL</th>
<th>MANUFACTURER</th>
<th>Toe Core</th>
<th>LOCATION USED</th>
<th>BEGINNING SERVICE DATE/STATION</th>
<th>DATES/REPLACEMENT OF SERVICE</th>
<th>DAYS/SERVICE BEFORE HOLE</th>
<th>NO./PLACES IN SERVICE</th>
<th>REDUCTION OF THICKNESS EXPOSED TO MAT.</th>
<th>TONS OF REFUSE EXPOSED TO MAT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Firmcast K54 castable refractory castable in carbon steel box, attached to pipe bend</td>
<td>8&quot; high</td>
<td>8&quot; pipe bend</td>
<td>Filler-A.P. Green Co., Mexico, Mo. Box-Meramec Plant</td>
<td>8&quot; pipe bend</td>
<td>X1D-XAD; X31; X41; X3J; X6J; X1E-XAE; X1F; X1G; X7G; X4X-XAC</td>
<td>1-23-73</td>
<td>2-1-73 **</td>
<td>8</td>
<td>20</td>
<td>Not Applicable</td>
<td>134.6</td>
</tr>
<tr>
<td>13</td>
<td>Devcon Flexane held in carbon steel box, attached to mitred pipe joint</td>
<td>8&quot; high</td>
<td>8&quot; pipeline joint</td>
<td>Filler-Midwest Tool &amp; Supply Co., St. Louis, Mo. Box-Meramec Plant</td>
<td>8&quot; pipeline joint</td>
<td>10&quot; mitred joint</td>
<td>1-23-73</td>
<td>6-26-73 ***</td>
<td>136</td>
<td>1</td>
<td>Not Applicable</td>
<td>356.9</td>
</tr>
<tr>
<td>14</td>
<td>Type 304 stainless steel and carbon steel plate</td>
<td>Total thickness of plates, 3/8&quot; + 3/8&quot; + 5&quot; + 5&quot;</td>
<td>Unknown</td>
<td>Meramec Plant</td>
<td>Inlet box of separator</td>
<td>8-14-72</td>
<td>1-19-73</td>
<td>75</td>
<td>1</td>
<td>16&quot;=100%</td>
<td>8668.8</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Permaneair plates made of tungsten carbide grit cast with an alloy matrix bond in a formed sheet steel pan</td>
<td>22&quot; x 14&quot; x 3/8&quot; thick</td>
<td>8&quot; pipe bend</td>
<td>Permanence Corporation, Detroit, Michiagan</td>
<td>Permanence Corporation, Detroit, Michigan</td>
<td>Inlet box of separator</td>
<td>2-13-74</td>
<td>No holes</td>
<td>No holes</td>
<td>246</td>
<td>1</td>
<td>1/32&quot;=8%</td>
</tr>
<tr>
<td>16</td>
<td>Duo-Plate liner in Rader Mark II elbow</td>
<td>3/4&quot; thick</td>
<td>8&quot; elbow X1H</td>
<td>Liner &amp; Elbow - Rader Pneumatics, Inc., Memphis, Tenn.</td>
<td>Liner &amp; Elbow - Rader Pneumatics, Inc., Memphis, Tenn.</td>
<td>2-2-73</td>
<td>3-4-74</td>
<td>85</td>
<td>1</td>
<td>3/8&quot;=100%</td>
<td>2135.7</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>&quot;Trowelon&quot; liner in Rader Mark II elbow</td>
<td>3/8&quot; thick</td>
<td>8&quot; elbow X3H</td>
<td>Liner &amp; Elbow - Rader Pneumatics, Inc., Memphis, Tenn.</td>
<td>Liner &amp; Elbow - Rader Pneumatics, Inc., Memphis, Tenn.,</td>
<td>3-1-73</td>
<td>3-27-74</td>
<td>76</td>
<td>1</td>
<td>3/8&quot;=100%</td>
<td>1957.01</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Alumina ceramic blocks attached to liner of Rader Mark II elbow</td>
<td>7/8&quot; thick</td>
<td>8&quot; elbow X3H</td>
<td>Liner &amp; Elbow - Rader Pneumatics-Memphis, Tenn.</td>
<td>Liner &amp; Elbow - Rader Pneumatics-Memphis, Tenn.</td>
<td>3-27-74</td>
<td>9-13-74</td>
<td>72</td>
<td>1</td>
<td>Blocks severely cracked &amp; broken</td>
<td>2300.9</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Abrasit tiles attached to liner of Rader Mark II elbow</td>
<td>11/2&quot; thick</td>
<td>8&quot; elbow X1H</td>
<td>Liner-N.H. Detrick Chicago, Ill. Elbow-Rader Pneumatics Memphis, Tenn.</td>
<td>Liner-N.H. Detrick Chicago, Ill. Elbow-Rader Pneumatics Memphis, Tenn.</td>
<td>8-27-74</td>
<td>No holes</td>
<td>96</td>
<td>1</td>
<td>11/2&quot;=10%</td>
<td>3772.5</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Replaceable 335 cast segments in a Rader Mark III elbow</td>
<td>5/8&quot; thick</td>
<td>8&quot; elbows XLA; X1A; X1B-XAB; X1C-XAC</td>
<td>Rader Pneumatics Memphis, Tenn.</td>
<td>Rader Pneumatics Memphis, Tenn.</td>
<td>11-25-74</td>
<td>No holes</td>
<td>107</td>
<td>12</td>
<td>0&quot;-0%</td>
<td>4600.1</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Ceram Core pipe bend with two spool pieces</td>
<td>8&quot; pipe bend, 266&quot; wall thickness, 125&quot; liner thickness</td>
<td>8&quot; pipe bend</td>
<td>A.O. Smith-Inland, Inc. Little Rock, Ark. Westfall Co. Sappington, Mo.</td>
<td>Westfall Co. Sappington, Mo.</td>
<td>9-28-73</td>
<td>No holes</td>
<td>197</td>
<td>1</td>
<td>1/16&quot;-16%</td>
<td>5791.3</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Ceram Surf compound applied to outside surface of pipe bend</td>
<td>3/4&quot; thick</td>
<td>8&quot; elbow X1J</td>
<td>A.O. Smith-Inland, Inc. Little Rock, Ark. Westfall Co. Sappington, Mo.</td>
<td>Westfall Co. Sappington, Mo.</td>
<td>11-10-75</td>
<td>No holes</td>
<td>12</td>
<td>12</td>
<td>0&quot;-0%</td>
<td>362.8</td>
<td></td>
</tr>
</tbody>
</table>

* Before first time plugged
** Pipe bend plugged with refuse
*** Box plugged with refuse
**** Use XI pipeline because of lower blower speed
***** Patch had no holes, pipe bend too badly eroded to support patch

NOTE: The operation of the Energy Recovery Project was terminated on November 30, 1975.
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<th>ITEM</th>
<th>DESCRIPTION</th>
<th>SIZE*</th>
<th>MANUFACTURER</th>
<th>SUPPLIER</th>
<th>LOCATION USED</th>
<th>BEGINNING SERVICE DATE</th>
<th>DATE/SERVICE DAMAGE</th>
<th>DAYS/SERVICE BEFORE HOLE</th>
<th>NO./PLACES IN SERVICE</th>
<th>REDUCTION OF THICKNESS IN. &amp; %</th>
<th>TONS OF REFUSE EXPOSED TO MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Tungsten carbide tile, fiber-glass tape and epoxy cement wrapped around pipe bend</td>
<td>1/4&quot; x 1/32&quot; thick</td>
<td>Kinton Carbide, Inc. Irwin, Penn.</td>
<td>Kinton Carbide, Inc. Irwin, Penn.</td>
<td>12&quot; pipeline, 1st pipe bend</td>
<td>1-16-74</td>
<td>1-23-74</td>
<td>6</td>
<td>1</td>
<td>No wear. Tiles broke loose from tape</td>
<td>362.8</td>
</tr>
<tr>
<td>24</td>
<td>Wearcarb tungsten carbide tiles attached with epoxy cement to steel patch for pipe bend</td>
<td>1/32&quot; thick</td>
<td>Teledyne Firth Sterling McKeesport, Penn.</td>
<td>Teledyne Firth Sterling McKeesport, Penn.</td>
<td>8&quot; pipe bend X40</td>
<td>4-27-74</td>
<td>No holes 3-17-75 *****</td>
<td>No holes 123</td>
<td>2</td>
<td>0%</td>
<td>3746.3</td>
</tr>
<tr>
<td>25</td>
<td>Stonhard Hi-Temp, 1800 lining applied to outside surface of pipe bend</td>
<td>3&quot; thick</td>
<td>Stonhard, Inc. Maple Shade, N.J.</td>
<td>Stonhard, Inc. Maple Shade, N.J.</td>
<td>8&quot; pipe bend X2F</td>
<td>7-16-74</td>
<td>No holes 12-1-73</td>
<td>No holes 60</td>
<td>1</td>
<td>15% - 50%</td>
<td>1979.4</td>
</tr>
<tr>
<td>26</td>
<td>Airco 388 electrodes deposited on steel patch for pipe bend</td>
<td>Single pass, about 1/8&quot; thick</td>
<td>Air Reduction Co. New York, N.Y.</td>
<td>Sanders Welding Supply Co.-St. Louis, Mo.</td>
<td>8&quot; pipe bend X3F</td>
<td>3-30-74</td>
<td>3-30-74</td>
<td>23</td>
<td>1</td>
<td>1&quot; - 100%</td>
<td>818.17</td>
</tr>
<tr>
<td>27</td>
<td>Vulcaloy 435 electrodes deposited on liner for Rader Mark II elbow</td>
<td>Single pass, about 1/8&quot; thick</td>
<td>Liner-Ceramalloy &amp; Research-Cleveland, Ohio Elbow-Rader Pneumatics, Memphis, Tenn.</td>
<td>Liner-Ceramalloy &amp; Research-Floresciant, Mo. Elbow-Rader Pneumatics, Memphis, Tenn.</td>
<td>8&quot; elbow X1H</td>
<td>4-3-74</td>
<td>8-27-74</td>
<td>33</td>
<td>1</td>
<td>1&quot; - 100%</td>
<td>1007.7</td>
</tr>
<tr>
<td>28</td>
<td>Lisman 10992 flame sprayed on steel patch for pipe bend</td>
<td>1/16&quot; thick</td>
<td>Eutectic Welding Alloys Chicago, Illinois</td>
<td>Eutectic Welding Alloys Chicago, Illinois</td>
<td>8&quot; pipe bend X1D</td>
<td>7-24-74</td>
<td>2-16-75</td>
<td>90</td>
<td>1</td>
<td>1/16&quot; - 100%</td>
<td>3390.44</td>
</tr>
<tr>
<td>29</td>
<td>Olinium 50 electrodes deposited on steel patch for pipe bend</td>
<td>Single pass, about 1/16&quot; thick</td>
<td>Eutectic Welding Alloys Chicago, Illinois</td>
<td>Eutectic Welding Alloys Chicago, Illinois</td>
<td>8&quot; pipe bend X3D</td>
<td>7-29-74</td>
<td>No holes 3-20-75 *****</td>
<td>No holes 96</td>
<td>1</td>
<td>1/16&quot; - 33%</td>
<td>3181.6</td>
</tr>
<tr>
<td>30</td>
<td>Vulcaloy 435 electrodes deposited on steel patch for pipe bend</td>
<td>Single pass, about 1/8&quot; thick</td>
<td>Ceramalloy &amp; Research-Cleveland, Ohio</td>
<td>Ceramalloy &amp; Research-Floresciant, Mo.</td>
<td>8&quot; pipe bend X4E</td>
<td>7-31-74</td>
<td>No holes 12-1-75</td>
<td>No holes 138</td>
<td>1</td>
<td>1/8&quot; - 50%</td>
<td>4481.8</td>
</tr>
<tr>
<td>31</td>
<td>Durafrax Platelets - (Sintered alumina) fiber-glass tape and epoxy cement wrapped around pipe bend</td>
<td>1/8&quot; thick</td>
<td>Carborundum Co.-Niagra Falls, New York</td>
<td>Carborundum Co.-Niagra Falls, New York</td>
<td>8&quot; pipe bend X3E, X3G</td>
<td>8-21-74</td>
<td>No holes 12-1-75</td>
<td>No holes 109</td>
<td>2</td>
<td>1/32&quot; - 6%</td>
<td>4222.7</td>
</tr>
<tr>
<td>32</td>
<td>Arflite alumina ceramic blocks attached to fabricated wearback</td>
<td>1&quot; thick</td>
<td>Ferro Electro Corp. Refractories &amp; Abrasives Div.</td>
<td>Iwan F. Eames Co. St. Louis, Mo.</td>
<td>10° mitred joints X1 pipe line</td>
<td>7-30-74</td>
<td>No holes 12-1-75</td>
<td>No holes 159</td>
<td>2</td>
<td>0° - 0%</td>
<td>6409.4</td>
</tr>
<tr>
<td>33</td>
<td>Dura Wear alumina ceramic blocks attached to fabricated wearback</td>
<td>1&quot; thick</td>
<td>Dura Wear Corporation Birmingham, Alabama</td>
<td>Dura Wear Corporation Birmingham, Alabama</td>
<td>10° mitred joints of 3X pipeline</td>
<td>6-19-75</td>
<td>No holes 12-1-75</td>
<td>No holes 16</td>
<td>2</td>
<td>0° - 0%</td>
<td>483.1</td>
</tr>
</tbody>
</table>

* Before first time plugged.
** Pipe bend plugged with refuse.
*** 1 ton = 0.9078 metric ton.
++++ Initial pipeline because of lower blower speed.
+++++ Patch had no holes, pipe bend too badly eroded to support patch.

NOTE: The operation of the Energy Recovery Project was terminated on November 30, 1975.
FIG. 1 PIPE BENDS OF THE PNEUMATIC PIPELINES
MERAMEC PLANT ENERGY RECOVERY PROJECT
Ceram Core is a glass fiber reinforced epoxy resin pipe with a special abrasion resistant liner composed of small spherical particles (see below) of high alumina ceramic, held in a matrix of epoxy.

**FIG. 2 CERAM CORE PIPE BEND USED IN A REFUSE PIPELINE AT THE MERAMEC PLANT**

**RADER MARK III ELBOW**

Another candidate for original equipment installations is the Rader Mark III elbow, manufactured for Rader Pneumatics, Inc. Pictured in Fig. 3, this elbow, Item 20, Table 1, is constructed of steel and has wear plates made of cast R35 alloy steel that are bolted to the elbow body for easy replacement when damaged. The unique design concentrates the material flow against the wear-resistant plates to minimize erosion of other parts of the elbow and the adjoining straight pipes. Its heavy weight makes it necessary for workmen to use lifting equipment during the installation period. The elbow was added to the pipeline by connecting flat steel flanges between the elbow and adjacent pipe. A total of 4600 tons (4176 t) of milled, solid waste were blown against the wear plates of this elbow, with a loss of 1/16 in. (1.59 mm) of material from the leading edges of each segment. The original thickness of each segment was 1/2 in. (12.7 mm). The only other wear was at the outlet of the elbow in the entrainment tip which had been fabricated from plain carbon steel. Future users of this elbow should require that the tip be made of R35 steel like the wear plates.

A very interesting note can be made about a desirable feature of the Rader Mark III elbow. Since the wear back is replaceable, almost all of the wear-resistant materials that have been successfully used in the program can be formed for direct attachment to the elbow or to a steel backing plate that can be attached to the elbow. For this reason, some of the materials were tested with these elbows.

**ABRESIST TILES AND CONTOURED SECTIONS**

An excellent material for abrasion resistance is Abresist, a volcanic basalt rock, Item 19, Table 1. Cast as either flat tiles or contoured sections, this material can be used to line the wear back of a Rader Mark III elbow or it can be used to line the entire internal surface of a steel pipe bend. Marketed in the United States by M. H. Detrick Co., this material is shown in the test installation using a Rader elbow in Fig. 4.

The tiles were attached to the steel backing plate with an epoxy cement supplied by Detrick that kept its bond throughout the test period. About 1/8 in. (3.18 mm) was worn from the original thickness of 1/4 in. (31.75 mm) by the 3772 tons (3424 t) of refuse that were carried through the elbow. Most of the erosion was concentrated in the area where the wear back made the sharpest turn. This damage was probably due to the severe impact of the refuse as it changed direction.
Rader MARK III elbow

PATENTED

EXPANSION CHAMBER
- allows material to be airborne immediately at elbow discharge

ELBOW RADIUS
- selected to provide best conveying efficiency and maximum wear life

INSPECTION DOOR
- replaceable
- directs material to center of pipe

ENTRAINMENT TIP
- replaceable
- directs material to center of pipe

REPLACEABLE BACK
- AR plate (standard)
- Ni-hard cast segments
- stainless steel
- any available rolled plate

WELDED BACK
- AR plate (standard)
- Mild steel plate
- for non-abrasive & non-corrosive applications

IMPACT SECTION
- controls & collects material before changing direction
- designed to minimize wear
- 10° impact angle controls material damage
- replaceable

SPACE REQ'D
- less than other long radius elbows
- interchangeable with other elbows.

FIG. 3

PATENTED
The most wear resistant material to be used in the pneumatic transport system is the Permawear plate, Item IS, Table I, made by Permanence Corporation. The plate consists of tungsten carbide grit cast with an alloy matrix bond in a formed sheet steel pan. Even though the test application used Permawear as a plate, the manufacturer is capable of casting the tungsten carbide grit into segments that can be bolted directly to a Rader Mark III elbow. The test installation was a flat transition area at the exit of the pneumatic transport pipe between the receiving building and the surge bin. All of the solid waste conveyed through the system was carried through this pipe and, hence, contacted the flat transition area. Holes were quickly eroded in this flat section. After several attempts using carbon steel and stainless steel plates, the Permawear plate was selected for a trial period. Bolted in place with nuts cast with the grit, the 22 in. x 14 in. (558.8 mm x 355.6 mm) plate had a thickness of 3/8 in. (0.79 mm) has been worn away from the original thickness by the 28,064 tons (25,475 t) of processed refuse blown against the plate. This is the largest amount of refuse exposed to any wear resistant material without significant damage.

Another form of tungsten tiles used was the Wearcarb tungsten carbide tiles, Item 24, Table 1. Manufactured by Teledyne Firth Sterling, these tiles were only 1/32 in. (0.79 mm) thick and came in two sizes of 1/2 in. x 1 in. and 1/2 in. x 1/2 in. (12.7 mm x 25.4 mm and 12.7 mm x 25.4 mm). These tiles can be attached to a rolled steel plate with epoxy cement or by brazing to form a wear back for a Rader Mark III elbow. This material was exposed to the abrasive refuse by attaching the tiles to a curved steel pipe patch with an epoxy cement. This patch was then placed over a hole in a pipe bend and held in place with steel bands. The patch was complete with a gasket to seal against leakage of transport air. The tiles resisted the erosion so well that the steel of the pipe bend around the patch was worn so thin that it could no longer support the patch. A total of 3749 tons (3403 t) of milled solid waste were exposed to these tiles without any noticeable wear. The only reason the patch was finally removed from service was the previously mentioned failure of the surrounding steel to support it.

A steel pipe bend patch was used again to expose the steel deposited by a wearfacing welding electrode to the abrasion of solid waste. Manufactured by Eutectic Welding Alloys, the Ultimium N112 electrode, Item 29, Table 1, was used to deposit stringer beads of tungsten carbide on a steel patch, as shown in Fig. 5. As in the previous case, this patch was used to cover a hole in a pipe bend and was held in place with steel straps. This electrode can be used in any number of areas that are suffering from wear. It can also be used to deposit tungsten carbide beads on a rolled steel wearback that can be attached to a Rader Mark III elbow. In the test installation,
the original thickness of 3/16 in. (4.76 mm) was worn to 1/8 in. (3.18 mm) by the 3181 tons (2888 t) of processed refuse that traveled through the elbow. The only real problem encountered in this method of testing the material was the severe distortion of the patch by the high heat as the electrode was burned. The patch had to be hammered and pulled into place in order to securely attach it to the pipe bend with a good seal.

**Vulcalloy 237 Welding Electrode**

Another welding electrode used in the same manner was the Vulcalloy 237 rod, Item 30, Table 1, made by Certanium Alloys and Research Co. Stringer beads of dense, combined chromium and columbium were laid out on a steel patch that was fastened over a hole in a pipe bend. The rod can also be used to hardface the carbon steel wearback for a Rader Mark III elbow. The tested material was originally 1/4 in. (6.35 mm) thick. About 1/8 in. (3.18 mm) of the welded metal was removed by the abrasion of the 4418 tons (4011 t) of refuse that came in contact with it. The same problem with heat distortion of the pipe bend patch required considerable work to complete the installation.

**Stonhard Hi-Temp 1800 Lining**

Stonhard Hi-Temp 1800 Lining, Item 25, Table 1, was a material used for patching a damaged elbow that was different from anything else that was ever tried. Made by Stonhard, Inc., Stonhard was a cementious substance in dry, granular form that required only the addition of water to produce a trowelable mortar. In order to test this material, a steel frame was welded around a hole in a steel pipe bend shown in Fig. 6. The hole in the pipe bend was covered with a thin piece of sheet steel. A mixture of Stonhard was troweled over the sheet steel to a thickness of 3 in. (76.2 mm) and was held in place while curing with the steel frame.

Possibly, this material could be used to line the wearback of a Rader Mark III elbow, but there are better materials suited for this type of application. Stonhard can really be recommended only for maintenance repairs and not for original installations. About 1 1/2 in. (38.1 mm) of Stonhard were gouged from the original thickness of 3 in. (76.2 mm) by the 1979 tons (1797 t) of refuse that were blown through the pipe bend. Even though there were no holes worn in the patch, if the thickness had been less than it was, a hole would have probably appeared.

**Durafrax Platelets**

An excellent means for repairing eroded pipe bends was the use of Durafrax Platelets, Item 31, Table 1. This material was a very fine grained, sintered 96 percent alumina ceramic that was manufactured as small tiles, 2 in. x 1 in. x 1/4 in. and 1 in. x 1 in. x 1/4 in. (50.8 mm x 25.4 mm x 6.35 mm and 25.4 mm x 25.4 mm x 6.35 mm). The platelets were attached to the pipe bend over the damaged area by using epoxy cement with alternate wrappings of fiberglass tape. The final layer of tape was coated with epoxy cement to make it structurally strong, as shown in Fig. 7. This repair method was quite easily utilized by one man and the pipe bend can usually be returned to service within one day. Even though the small tiles were used in the prototype operation, the larger Durafrax blocks could have easily been used to line a rolled steel plate to form a wearback for a Rader Mark III elbow. These blocks could be attached with epoxy cement or held by plug welding of the steel insert. A total of 4222 tons (3833 t) of refuse were conveyed through the repaired elbow with only a loss of 1/32 in. (0.79 mm) from the original thickness of 1/2 in. (12.7 mm). These good results indicate that the material, Durafrax, can successfully resist the abrasion of processed solid waste no matter what size blocks or tiles are used.
ARLCITE BLOCKS

Another ceramic used to resist abrasion was the Arlcite alumina ceramic blocks, Item 32, Table 1, made by Ferro Electro Corporation, Refractories and Abrasives Division. Consisting of at least 85 percent sintered alumina, these blocks were attached with epoxy cement to a wearback that was fabricated by Meramec Plant personnel. This wearback was bolted to a rectangular box that was built into a damaged pipe at a 10 deg. mitred joint. This box can be seen in Fig. 8. These blocks could also be easily attached to a wearback for a Rader Mark III elbow, like some of the other previously mentioned materials. About 6409 tons (5818 t) of milled solid waste were blown against the Arlcite blocks with no measurable loss from the original thickness of 1 in. (25.4 mm). However, this application was not nearly as severe as the others previously discussed because the joint was only 10 deg. instead of 45 deg. or 90 deg. This 10 deg. joint greatly reduced the change of direction of the refuse steam, and thus reduced the abrasive wear.

The remaining two materials that will be discussed were installed shortly before the Energy Recovery Project was terminated. They both had a minimal amount of exposure with no detectable damage. Even so, these materials will be mentioned for informational purposes.

CERA DUR TILES

Cera Dur, Item 33, Table 1, is a ceramic produced by Dura Wear Corporation that is formed into tiles. Composed of 85 percent metallic oxide, this material can be attached to the rolled wearback of a Rader Mark III elbow by welding or with epoxy cements. Again, the test installation was a rectangular box built at a 10 deg. mitred joint in the pneumatic pipeline, as shown in Fig. 9. The tiles were anchored to the wearback by welding the steel insert to the steel plate. No material was removed by the 483 tons (438 t) of refuse that were impacted against the tiles.
A maintenance compound that can be used to line a steel pipe bend or a wearback for a Rader Mark III elbow is Ceram Surf, Item 22, Table 1. Manufactured by A. O. Smith-Inland, the makers of Ceram Core pipe, this material is composed of small spherical particles of high alumina ceramic held in an epoxy base. The hardener is kept separate until the Ceram Surf is to be applied. The base and hardener are mixed and applied to the surface to be protected. The test installation involved the attachment of this material to the outside surface of a 1/2 in. (12.7 mm) steel patch that covered a hole in a pipe bend. With only 362 tons (329 t) of refuse transported through this pipe bend, it is doubtful that the Ceram Surf beads have been exposed to enough of the refuse steam to draw any conclusions.

CONCLUSIONS

The results of this study indicate that there are several materials that are commercially available to resist the abrasive particles that are contained in processed refuse. The author does not suggest that these are the only materials applicable to this type of service. No doubt, there are other substances that could be used, but did not fall within the scope of this program.

The selection of the material for a specific application depends, in large part, on cost, shape, structural support, and accessibility for maintenance. This selection will have to be left to the design or maintenance engineer as he comes to grips with the problem. Hopefully, this paper has shown what groundwork has been done and that it can make the search for a wear resistant material a little easier.

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Discussion by

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The author presents an extensive evaluation of the performance of abrasion resistant materials used in handling processed refuse. What this evaluation lacks in the way of insuring controlled or similar conditions for the materials tested is compensated for in the sheer number of materials tested.

The first 12 months of operation of the air classified refuse ACR (i.e., RDF) receiving, storage, and firing equipment at Wisconsin Electric Power Company’s Oak Creek Power Plant has shown abrasion of pneumatic conveying lines somewhat comparable to that illustrated by the author.

The pneumatic conveying system used to retrieve refuse from the Atlas storage bin for firing in two 310 MW suspension fired steam generators at Oak Creek is composed of approximately 1800 ft (548 m) of nominal 10 in. (25.4 cm) diameter, schedule 40, low carbon steel, pipe. Rader Mark III elbows with cast R35 alloy steel replaceable wear backs are used at all changes of direction. Four Rader Model 09 diverting valves are used to direct refuse to either of the two furnaces.

By March of 1978, a total of 31,000 tons of refuse were handled at Oak Creek. This is approximately 7,700 tons per conveying line, at an average feed rate of 5 to 10 tons per hour per conveying line.

Fifty separate locations in the conveying system are periodically being measured with an ultrasonic device in an attempt to monitor wear rates. As of March, 1978 the highest amounts of wear are noted at several of the Mark III elbows that are mounted on their side. Holes wear through the unprotected lower side of the elbow. This is particularly true for such elbows installed at the ends of long, straight, horizontal runs of pipe where glass and other abrasives are allowed to drop out to the bottom of the pipe. New wear back segments with extensions to protect the elbow sides are to be installed during June, 1978 in order to correct this problem.

The Rader Model 09 valves have shown high wear rates (30 percent reduction of wall thickness) as these are only made of low carbon steel. Abrasion resistant alternatives are being considered for these valves.

Straight horizontal pipe runs have shown a 10 to 12 percent reduction in wall thickness at the bottom of the pipe, and 3 to 6 percent reduction at the top of the pipe.

Wear of the R35 cast steel wear back plates for the Rader Mark III elbows has been generally less than 5 percent of the material thickness.

It is hoped that these brief comments can be a useful addition to the evaluation of abrasion resistant materials as presented in this paper.

AUTHOR'S REPLY

To James W. Keller

The Energy Recovery Project was conceived and constructed to be a low-cost simple system for firing refuse in an electric utility size boiler. One of the first problems that was encountered with the system was the rapid erosion of the transport pipe bends. Unfortunately, the construction of the system did not lend itself to controlled tests of materials to resist this erosion.

The main purpose of testing so many different materials was to find one that could be used as soon as possible within the system before its operation was terminated by the formal ending of the project. As reported in my paper, several of these materials were found to be well suited to resisting refuse abrasion and were used extensively.

I am happy to see that even though the Energy Recovery Project in St. Louis has been terminated, one of the materials experimented with in our system has also proven to be highly wear-resistant to refuse abrasion at the Oak Creek Power Plant. I hope that additional work will be performed in testing these materials within other refuse handling systems around the country.