Saving Energy with Brick, Refractory, Insulation and Lagging

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Abstract

For the refuse-to-energy industry, "Saving Energy with Brick, Refractory, Insulation and Lagging (BRIL)" is as simply as understanding it's refuse boiler. A refuse-fired boiler has many components to make it do what it is supposed to do. BRIL is a key component of the boiler just as important as the tubes that carry the water or steam, the soot blowers that keep the unit free of fly ash or dust, the burners that burn the fuel efficiently, the economizers that recover heat and pre-heat the water, and many more such systems found on, in and around the boiler. They all help keep the boiler operating thermally and energy efficient. Proper BRIL material selection and installation can have an energy savings of 5-7% per year in fuel consumption. That is why experts say, "brick, refractory, insulation, and lagging (BRIL) installed to save energy, saves money at a rate that is essential for efficient plant operation."

Background

The boiler is at the epicenter of the entire refuse-to-energy industry. Not only is the boiler important for burning refuse, mass or refuse-derived, it also acts as an energy source supplying steam and electricity. It would than seem appropriate that the plants would want that valuable resource to be as energy efficient as possible. To obtain peak energy efficiency, the refuse-fired boiler must have the proper brick, refractory, insulation and lagging, the true energy saver.

To help us understand, and appreciate the BRIL that exists on the refuse-fired boilers of today it is helpful to see how the designs of the boilers and the bril changed over time. For this paper, we shall follow the development of the Kraft Recovery boiler, which was the first type of boiler to use solid waste (of a sort) as its main source of fuel. The Kraft recovery process was developed in Danzing, Germany in 1853. In 1907, the Kraft recovery process was introduced in North America. By 1929, G.H. Tomlinson and Babcock & Wilcox Canada had designed and supplied the first Tomlinson boiler. This black liquor recovery boiler had refractory furnace walls. Later, around 1934, a completely water-cooled design was developed.

The BRIL design on the recovery boilers changed as the tube construction changed. As the mill's smelt requirements increased so too did the recovery boiler. As the boiler increased in size, pressure, and temperature more was expected of the refractory and insulation being used on the recovery boiler.
The early recovery boilers had loose tube construction and required refractory on the backside of the furnace wall tubes to keep the fire inside the furnace box cavity. Insulation and casing was then installed over the refractory. The refractory, insulation and casing worked together to keep the recovery boiler thermally and energy efficient.

The inner cased boiler design evolved about the same time as the flat studded boiler. These recovery boilers had tangent tube construction and required only a smear coat of refractory over the outside of the furnace wall tubes. Over the refractory an inner casing was installed. The insulation and outer casing kept the boiler thermally efficient. The refractory and inner casing acted together to help keep the boiler energy efficient by keeping the fire inside the furnace box cavity while allowing heat from the fire to be transferred to the tubes.
Then in 1963 membrane tube construction replaced the flat studded and tangent tube design. The membrane tube walls (tubes seal welded into panels) would now prevent the fire from escaping from the furnace cavity. Refractory would still be required to keep the boiler energy efficient by sealing gaps, openings, penetrations, and for filling wall boxes (primary and secondary air ports, smelt spout wall boxes, oscillator and burner openings etc.). The refractory and insulation would prevent heat loss and thus keep the boiler operating efficiently. The external insulation and lagging (replacing the outer casing design) would keep the recovery boiler thermally efficient.

With the development of the membrane tube wall construction new fuel options began to be explored. By the late 1970’s and early 1980’s, refuse fired boilers were developed. This new type of boiler design was developed due in part because of the growing disposal costs for landfills, the passage of the Public Utility Regulatory Policies Act of 1978, and an increase in demand for electric power in the United States. Like the bubbling bed and fluid bed boilers, trash or refuse boilers required refractory and brick inside the furnace to protect the tube surface from the environment created by the new fuels. The refractory and brick not only had to protect the tubes but also must have a certain thermal conductivity in order for the boiler to operate correctly. With the development of these new types of boilers, brick and refractory once again became a critical component of boiler and bril designs.
To accomplish thermal and energy efficiency means knowing your refuse-to-energy boilers and your BRIL. Every nook, cranny, exposed wall surface, hot flue or duct, wind box, pipe or exposed tube will have some sort of bril on it. Unfortunately, there is a definite lack of appreciation for brick, refractory, insulation and lagging as an energy saver. This lack of appreciation or the lack of awareness must be overcome in order to help control energy loss and to help keep the refuse boiler operating efficiently.

**The Fundamentals in bril design begins with Thermal Calculations and ends with Savings:**

The proper design and installation procedures for the refractory and/or insulation for a refuse boiler are critical. Yet, how many in the refuse-to-energy industry know or understand thermal calculations? There are six key factors for understanding heat flow, or thermal calculations and for saving energy and money. The six important factors are wind velocity, ambient air temperature, surface temperature, "K" value, emissivity factor, and the operating temperature. Proper calculation of the insulation and refractory (thickness and material types) will save the refuse-to-waste industry money at the initial installation because you will only pay for what you need. As a long-term investment, the refuse-to-energy industry will save energy and money by minimizing the amount of heat loss that radiates from the outer casings or lagging surfaces. By understanding heat flow calculations, the refuse-to-energy industry will use less fuel to reach and maintain their boiler's operating conditions because they will have ensured the right bril designs for their boilers. Again, the refuse boiler (or any steam generating boiler) will never be energy efficient or may not operate at all if the brick, refractory, insulation and/or lagging (BRIL) is not designed and installed correctly.
For example:

Refractory material is usually required on the lower furnace walls and floor on the refuse or trash boilers to protect the tubes from the environment created by the burning of refuse. If the refractory material does not do its job to protect the tubes from the environment created by the burning of the trash or refuse the boiler will have to be shut down in order to prevent extensive tube damage. Plus, any down time of the refuse boiler in a facility means loss of electric production and money to the plant.

Refractory Mixing and Installation

Without proper refractory designs, the refuse boiler would not and will not be energy efficient. Though refractory may be the smallest of the BRIL and boiler components it is the key to saving energy for the steam-generating refuse boiler. Unlike insulation and lagging, if the refractory fails to do its job the boiler will not operate efficiently or may not operate at all. So the first step in ensuring energy savings after proper refractory material selection (see below) is mixing.

Mixing your refractory material is the first step in assuring proper material installation. In order to ensure proper mixing you must know five things. You must know 1) how much water to add to the refractory mix, 2) the temperature of the water, 3) type of water, 4) pot life, and 5) the shelf life of the refractory material. Any mistake of one or more of these important mixing steps will inhibit or stop the refractory material from reaching its full strength.

Because refractory materials are such an important component of the refuse boiler it will also be important for you to know and understand the differences of applications. In order to mix the refractory material properly, you must know how the material is to be applied and there are basically three ways to install refractory materials:

1) The **gunning application**, this is where the water is mixed at the discharge nozzle or back at the charging chamber.

2) The **trowel application** is a hand-applied method and is used for installing thin linings. To ensure that the right amount of water has been added for trowel application a “ball in hand” test can be used. A small ball of the refractory mix is made and tossed twelve inches into the air several times, catching it on the flat palm of the hand. If the refractory breaks apart when it hits the palm, it is too dry. If it flattens out, it is too wet for a dense castable but ok for an insulating castable. If it flows between the fingers it is too wet for either the dense or the insulating castable.

3) The **cast or pour method of application**. This application is the most common of all the applications used in the boiler industry for installing refractory. This type of application requires forms to retain the material in place. The refractory mix will be much wetter than that used for trowel application. The refractory mix must flow into the required area and so must be soupy. For wall boxes and deep pours, rodding or vibrating is required to assure that all air bubbles is removed.

As you can tell, refractory materials are very temperamental. You need to know the amount of water, temperature of the water, type of water, the pot life, and the shelf life. Add to all this is the fact that the material must be mixed and installed at the work location makes it even more difficult. Anyone that has been to a jobsite can attest to how difficult the working conditions can be.
Finally, the refractory material must be properly cured and dried. Curing is done right after the material is installed. It is the process by which the refractory material is kept wet or the surrounding atmosphere humid for a twenty-four hour period. Curing allows the refractory material to develop proper strength. Drying occurs after curing and can be done during the normal start-up of the boiler. The drying, or bake-out, will assure that the refractory material reaches full strength.

So you can see that it pays to pay attention to your refractory installation. Though refractory may be the smallest of the boiler or BRIL components, improper material specification or installation can affect the entire project or the overall boiler operation and efficiency.

**Proper Material Selection**

To avoid “shut down” the first step is assuring proper refractory and insulation material selection and design. You can never separate material selection and design. People have tried but in the end it does not work. Design and material selection must go hand in hand. When we talk about design in regard to insulation and refractory materials, we are talking about thermal calculation. This means that the refuse-to-energy industry must understand thermal calculations.

While not the whole story, the following might simply shed some light on how to determine the right insulation and refractory requirements for maximum savings and ensuring energy efficiency for the refuse boiler used in the refuse-to-energy industry.

**Calculating Insulation & Refractory Thickness**

A good way, for those in the refuse-to-energy industry, to understand thermal calculations for calculating insulation and refractory material thickness is to use good old-fashioned hand calculations. The formula below can be used for flat surfaces to calculate the minimum insulation thickness to meet the specified surface temperature:

\[
\text{thickness} = \left[ \frac{(\text{operating deg } F - \text{surface deg } F)}{\text{(convection + radiation)}} \right] \times (K \text{ value})
\]

The formula must be broken down further:

\[
\text{thickness} = \left[ \frac{(\text{operating deg } F - \text{surface deg } F)}{(1 + 0.225 \times \text{velocity (fps)}) \times (\text{surface deg } F - \text{ambient deg } F) + (0.1714 \times \text{EMISSIVITY}) \times (\text{surface deg } F - 620) \times (\text{ambient deg } F - 620)}{100^4} \right] \times (K \text{ value})
\]

This thermal calculation seems quite complicated, and with all the calculation software (like NAIMA’s 3E+ program) on the market today we should be glad that we no longer have to hand calculate. However, these computer programs require the same input to calculate heat flow. They all ask for velocity, ambient air temperature, surface temperature, operating temperature and the emittance factor. Most of these computer programs have built-in thermal conductivity values (K values) for the types of insulation and refractory to be used or can be easily inputted. The same criteria also applies when using the alternative empirical methods found in ASME Performance Test Codes 4 and 33 for boilers located inside buildings where natural convection predominates.
Variables of Calculation

First, it must be clearly understood that when dealing with external heat flow and insulation the operating temperatures will vary depending on the medium that is being used for heat transfer. For the boiler, the operating temperature will be based on the saturation temperature derived from the operating steam pressure of the boiler. For all other areas such as the boiler casing, wind box, flues, ducts, air heaters, etc it will be based on the operating temperature of the gas or air at that point in the process.

So what really effects the insulation and refractory thickness calculation? The most obvious is the K value. A higher K value causes the calculation to have a greater thickness. By using the mean value you will get a lower K value, therefore, a smaller thickness of material. To find the K value one must:

1. Find the mean temperature \( \text{operating temp. + surface temp.} \) \( \frac{2}{2} \)
2. Identify value of K on published charts

Unfortunately, the K value of insulation has not changed dramatically over the years. As R. L. Schneider, a pioneer in heat transfer calculations, wrote “...since it is harder to keep improving insulation by decreasing the K (thermal conductivity), let’s increase the thickness when necessary.”¹ If this is still true, then what other variable or variables can affect the outcome of the thickness calculation?

- **Ambient air** – this is not a fixed value and so can have an affect upon the thickness calculation. Normally the ambient air value is between 70 to 80 deg F. *The lower the ambient air temperature the lower or smaller the thickness required to meet the specified surface temperature, but more heat will leave the boiler stealing efficiency.*
- **Surface temperature** – this is not a fixed value and so can have an affect upon the thickness calculation. The industry standard for an acceptable surface temperature is anywhere between 120 and 140 deg. F. *The higher the surface temperature the lower the thickness.* Little heat would leave the boiler if the casing surface is specified near the ambient temperature, but that would be very expensive to achieve.
- **Operating temperature** – this is usually a fixed or a set value based on the size of the refuse boiler and so is considered a constant not a variable in the calculation formula.
- **Emittance factor** – this is not a fixed value and so can have an affect upon the thickness calculation (especially because of its location in the denominator of the formula). *The lower the emittance factor the less heat transferred and better efficiency would be achieved.*
- **External wind velocity** - this is not a fixed value and so can have an affect upon the thickness calibration (especially because of its location in the denominator of the formula). *The higher the wind velocity the greater the heat loss.* Please note that this can apply to a natural or forced convection condition. The process of convection (forced or natural) is so closely related to heat transmission that it has been accepted as a means of heat transfer regardless of what type of convection is occurring on the surface.

One or combination of any of the above may have an affect upon the thermal calibration. So it will pay to pay attention to what goes into a thermal calculation.

Factoring Economic and Energy Savings
By understanding how thermal calculations are done those in the refuse-to-energy industry can then compare labor and material costs at various thickness based on the different values of design conditions (i.e. 130 deg. F surface temperature to 120 deg F, zero wind velocity to 50fpm, .05 emittance factor to .2, etc.).

For example:
Say you are designing the insulation and lagging system for a long flow economizer casing on the back of your refuse boiler: The design parameters are:

- Ambient air: 80 deg F
- External wind velocity: 50fpm
- Surface temperature: 130 deg F
- Emittance factor of: .05 for aluminum lagging
- Operating gas temperature: 700 deg. F
- Insulation type: Mineral Wool 8#/cf board, meeting ASTM C-612 class 4

Using the above information with the previously mentioned formula, the minimum thickness required would be approximately 4” thick (see sample calibration below).

<table>
<thead>
<tr>
<th>SAMPLE INSULATION THICKNESS CALCULATION</th>
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</thead>
<tbody>
<tr>
<td>Emissivity factor for aluminum lagging =</td>
</tr>
<tr>
<td>Operating temperature deg F =</td>
</tr>
<tr>
<td>Surface temperature deg F =</td>
</tr>
<tr>
<td>Ambient air temperature =</td>
</tr>
<tr>
<td>External wind velocity fpm =</td>
</tr>
<tr>
<td>External wind velocity fps =</td>
</tr>
<tr>
<td>Mean temperature = (operating temperature + surface temperature)/2 = deg F</td>
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<tr>
<td>Type of insulation being used = mineral wool board ASTM C-612 class 4 nominal 8 # density</td>
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<tr>
<td>K value of the insulation =</td>
</tr>
<tr>
<td>Operating temp. – surface temp. =</td>
</tr>
<tr>
<td>Convection =</td>
</tr>
<tr>
<td>Radiation =</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INSULATION THICKNESS CALCULATION (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>thickness = [ \frac{(\text{operating deg F} - \text{surface deg F})}{(1 + 0.225 \times \text{velocity (fps)})^2 \times (\text{surfacke deg F} - \text{ambient deg F}) + (0.1714 \times \text{EMISSIVITY})^2 \times (\text{surface deg F} + 460)^2 \times (\text{ambient deg F} + 460)}{100} ] \times (K value)</td>
</tr>
<tr>
<td>Insulation thickness used = (inches)</td>
</tr>
</tbody>
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By changing the external wind velocity to zero, or still air, and decreasing the surface temperature to 120 deg. F would increase the insulation thickness to 6” (see sample calculation below).
SAMPLE INSULATION THICKNESS CALCULATION

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<table>
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<tbody>
<tr>
<td>Emissivity factor for aluminum lagging =</td>
<td>0.05</td>
</tr>
<tr>
<td>Operating temperature deg F =</td>
<td>700</td>
</tr>
<tr>
<td>Surface temperature deg F =</td>
<td>120</td>
</tr>
<tr>
<td>Ambient air temperature =</td>
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<tr>
<td>External wind velocity fpm =</td>
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</tr>
<tr>
<td>External wind velocity fps =</td>
<td>0</td>
</tr>
<tr>
<td>Mean temperature = (operating temperature + surface temperature)/2= deg F</td>
<td>410</td>
</tr>
<tr>
<td>Type of insulation being used = mineral wool board ASTM C-612 class 4 nominal 8 # density</td>
<td></td>
</tr>
<tr>
<td>K value of the insulation =</td>
<td>0.425</td>
</tr>
<tr>
<td>Operating temp. – surface temp. =</td>
<td>580</td>
</tr>
<tr>
<td>Convection =</td>
<td>40.00</td>
</tr>
<tr>
<td>Radiation =</td>
<td>2.4111</td>
</tr>
<tr>
<td>INSULATION THICKNESS CALCULATION (inches)</td>
<td>5.81</td>
</tr>
</tbody>
</table>

\[
\text{thickness} = \left( \frac{(\text{operating deg F} - \text{surface deg F}) \times (1 + 0.225 \times \text{velocity (fps)} + (\text{surface deg F} - \text{ambient deg F}) \times (0.1714 \times \text{EMISSIVITY})^3 \times (106^4)}{(106^4 \times (\text{ambient deg F} + 460)^4)} \right) \times (\text{K value})
\]

The material costs would increase approximately $0.34 to $0.44 per square foot and the labor cost, because the application would go from a single layer to a double layer application, increased about $2.04 per square foot (using $38.50 labor rate per hour x .053 man-hours per square foot).

This is an over simplified example because the dollar amounts do not take into account the other factors that affect the overall cost such as stiffener sizes, casing configuration, and the insulation and lagging application. However, it does reflect a total labor and material cost due to a change in one or more of the key factors in the thermal calculation program. Understanding what is a correct value or an incorrect value can in the end save the refuse-to-energy industry money and help assure that you have the proper design for your insulation and refractory systems. The hard part is to relate that to energy savings. J. F. Malloy, author of Thermal Insulation and regarded as one of the most creative minds in the field of insulation, wrote [the greater the cost of insulation the smaller the cost of heat loss]. What Mr. Malloy was saying is that you will be saving on heat loss because the insulation thickness had been increased and thus will save energy.

A Little Knowledge Pays Off

With a better understanding of thermal calculations those in the refuse-to-energy industry can do a better job of evaluating insulation and refractory designs with confidence. The next time a discussion comes around about thermal calculations they can ask pointed questions such as:

- Was the K value based on mean temperature?
- What was the external wind velocity used?
- What emittance was used to calculate the insulation and refractory thickness?
• What surface temperature did you limit your design to?
• What ambient air temperature are the calculations based on?

Knowledge is everything! Knowing more about the calculations can help assure the proper material type and thickness. If, for example, an incorrect emissivity or external wind velocity factor is being used you would know that this can have a serious affect upon the insulation and/or refractory design. By choosing the correct factors and criteria in designing your insulation and refractory thickness you can keep your initial installation costs down. You will only pay for what you need (short-term cost savings). In addition, heat loss in your plant will be minimized, which keeps fuel costs down (long-term energy savings). The end result is a thermally efficient boiler that had a cost-effective installation. Having the proper design is why Mr. Malloy adds, “Thermal insulation installed to save energy also saves money at the rate that is essential for efficient plant operation.”

Energy Savings

Improper brick, refractory, insulation and/or lagging (BRIL) installation and design has a direct affect upon the amount of energy being used and/or lost at your plants. The ability to keep installation costs down and having the right design for maximizing energy efficiency is directly proportional to the amount of fuel being used by the refuse boiler. That is why experts say, “Brick, Refractory, Insulation, and Lagging installed to save energy also saves money at the rate that is essential for efficient plant operation.”

Environmental Savings

The ability to keep installation costs down and having the right BRIL design for maximizing energy efficiency is directly proportional to the amount of fuel being used at a facility. Yet, more is expected from these facilities than just saving energy. They are also expected to save the environment too.

Expensive Selective Catalytic Reduction Systems or otherwise called SCRS need to be installed to control NOx emissions. Yet these SCRS will not operate correctly unless the gas temperature remains at or above the design operating temperature. So it will be imperative that the insulation and lagging be properly designed and installed to prevent excessive heat loss. Also, the boiler itself must be operating efficiently in order to maintain the proper exit gas temperature. For an average SCR, supply and install, could cost as much as fifty million dollars. Properly designed and installed insulation and lagging will be imperative for these, very expensive, air pollution equipment to work properly.

Low NOx burners may need to be installed. This is widely done around the industry and can amount to a very large sum of money. For an average supply and install project it could be as much as $120,000 per low NOx burner. Refractory materials will be required in the wallboxes, in the burner tube crotches, or on the of the furnace walls. Improper material selection or installation could have an adverse affect upon the efficiency of these burners.

And finally, in some cases, hot precipitators, baghouses, scrubbers, and flue work may need to be installed to reduce the overall air pollution at these facilities. For these types of air pollution equipment, insulation and lagging must be properly designed and install for them to operate efficiently.
Conclusion

What is to be done? A refuse-to-energy plant should:

1. Review the brick, refractory, insulation and lagging specifications and application procedures to make sure they are up to date and current with modern industry practices and standards.
2. Have a plant inspection or assessment done to find where you may be losing energy (heat loss).
3. Maintain the brick and refractory linings inside the furnace areas to protect the tube surfaces from the corrosive affects created by the burning of refuse. Tube wall corrosion maybe the number one reason for boiler shut down and rising maintenance repair costs.

The more the refuse-to-energy industry and the plant facility know about brick, refractory, insulation and lagging (BRIL) the more energy (fuel consumption and steam temperature) they will save. Even though there may be more garbage at a facility than they can process that does not mitigate or detract from the overall importance of boiler efficiency and energy savings. It has been reported that President Bush said, “Energy is a problem that requires action- not politics-not excuses, but action.” It is therefore imperative, and a national concern, to do everything possible to design and maintain an energy efficient refuse boiler. Your steam-generating refuse boiler is designed to operate at maximum efficiency when all of its design conditions (surface temperatures, heat loss, gas outlet temperature, etc) are met. To do anything less, or to allow the boiler to fall into repair, is failing to see the bigger picture. We must all participate in the endeavor to save energy for our country. For the refuse-to-energy industry that begins with their brick, refractory, insulation, and lagging. If by making your boiler more efficient you use less garbage to meet your steam and heat requirements then build more boilers to make more electricity available for the consumer.

BRICK, REFRACTORY, INSULATION, and LAGGING (BRIL) when designed and installed properly on your refuse-fired boiler, will help to assure the boiler is operating at peak efficiency. When the boiler is operating at peak efficiency it will the use the least amount of fuel and thus will be saving energy. The alternative is an inefficient plant where fuel (mass or refuse-derived) is being wasted.

References: