Water gauge, Flue Plate Stiffeners, and Insulation Systems Design Considerations

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Abstract
Tremendous money is wasted due to the lack of attention to the water gauge and flue plate stiffeners, and their impact on the insulation and lagging design. The design and installation of an insulation and lagging system will depend heavily upon the flue or duct stiffener arrangement. The stiffener arrangement is determined by many factors including the water gauge of the flue or duct plate design. The stiffener pattern and size is the first thing you consider when designing an insulation and lagging system. Therefore, it is imperative to understand how the size, shape and pattern of the external stiffeners are developed. The stiffener sizing of yesterday was based on a much lower water gauge pressure and allowed the insulation to be placed between the stiffeners without having to cut-to-fit. The stiffeners being designed today are quite large and much farther apart. This is due in part to the water gauge number being used in the design calculations and because they have not considered the required insulation thickness and application. A well designed and installed insulation and lagging system will save money and energy at a rate that is essential for an efficient plant operation. This is especially true when adding a selective catalytic reduction system (SCR) or a selective non catalytic reduction system (SNCR) to the back end of a steam-generating unit. The insulation and lagging system is critical for these air pollution systems to operate correctly.

Background
Urban smog is worsened by nitrogen oxide emissions (NOx), and power plants have been identified as the largest stationary source of nitrogen oxide emissions. Due to regulation, agreement or emission trading, many power plants and municipal waste combustors must lower their NOx emissions. One way to reduce NOx emissions is by installing a Selective Catalytic Reactor (SCR) or Selective Non Catalytic Reactor (SNCR) to the back end of their boiler or combustor. An SNCR or SCR system is basically a large box placed in the gas flow that removes NOx from the flue gas before it exits the stack. Adding an SCR or SNCR system to an existing power plant will also mean adding a large amount of flue plate.

An average SNCR or SCR system being installed at an existing power plant can cost millions of dollars (including insulation and lagging). An improperly designed and/or installed insulation and lagging system will have an adverse effect upon the SNCR or SCR's ability to operate correctly. If the flue gas temperature drops below the designed operating temperature than the SCR or SNCR will not remove all of the NOx emissions from the flue gas and you won't meet your NOx emission requirements. So it will be imperative that these air pollution systems be insulated and lagged correctly.

The design and installation of a lagging and insulation system will depend heavily upon the stiffener arrangement. The very first thing you do when designing a lagging and insulation system is to review the area to be insulated and look at the stiffener size and pattern. The stiffener arrangement will depend upon many factors including the water gauge that the system is to be designed for.
FLUE AND DUCT DESIGN

There is a lot of design work involved when designing a flue or duct arrangement or the casing for an SCR or SNCR box that the gas will pass through. Along with the physical restrictions will be other factors that will affect the design such as the gas temperature and the water gauge. Each of these factors (physical restrictions, gas temperature, and water gauge) will affect the insulation and lagging design. Of all the factors, in my opinion, water gauge is the most important and least understood.

The term “water gauge” refers to an instrument that indicates the level of water, as in a boiler, tank, reservoir, or stream. The amount of water shown on the water gauge instrument is measured in “inches.” That alone does not tell us enough but it’s a good place to start.

Stiffener Sizing and Spacing

Stiffener size is based primarily on three essential items: span, pressure, and temperature and is limited by stress or deflection. So the question arises: How to determine the sizing of stiffeners?

After a layout has been completed for a flue or duct system the individual components must be designed from a structural standpoint to withstand forces due to the following:

1. Internal static pressure of the contained fluid (in this case spent gas or air)
2. Transient pressure designated for the system (where we find reference to water gauge)
3. Dead weight of plate, stiffeners, insulation, lagging, etc.
4. Wind and seismic loading
5. Expansion joint actuation forces
6. Ash accumulation (if applicable)
7. Load transfer from other equipment

All of these factors must be taken into account for the design of a flue or duct stiffener sizing along with any and all governing codes. A typical example of the minimum amount of information needed for a horizontal flue or duct plate stiffener calculation would be as follows:

- Duct size = 8 ft high x 16 ft wide x 3/16" plate
- Stiffener spacing = 24"
- Temperature = 800 deg F
- Water Gauge Pressure at steady state = $+25' H_2O$
- Water Gauge Pressure at transient state = $\pm 35' H_2O$
- Flue wall weight $\approx 5' H_2O$
- Bending Stress = 12,000 PSI
- Allowable Stress Level = 19,000 PSI
- Span = 8 ft = 96 inches

You will notice the absence of any reference to insulation thickness or insulation and lagging system requirements. It is not my intent to make the reader into design engineers but to show how the development of flue or duct stiffener sizing and spacing affects insulation and lagging design.

Using the above information design engineers will be able to determine the size of the stiffener and spacing of the stiffeners by using typical design formulas (see APPENDIX - Eq. (1) and Eq. (2)):

The designers would then would go to a book like the AISC Manual of the American Institute of Steel Construction to find a stiffener size that is close to the above calculation. In this case it would be a 5" x 5" x 3/8" angle that has a Z equal to 2.4 cubic inches.

The designers would then take their chosen angle
size and recalculate to see if their chosen angle's bending stress is less than the allowable stress level value. There are many other steps not shown, such as the calculation of the Transient Bending or Negative Pressure, but at least you begin to understand how complicated the calculation process is for sizing and spacing of stiffeners.

There are two key elements in the formulas that have a direct affect upon insulation and lagging systems. They are stiffener spacing and water gauge pressure [refer to Eq. (1) and (2)].

Today, all such calculations are being done on a computer. Years ago those doing the calibrations considered the insulation and lagging systems when determining their stiffener sizing and spacing. That is not the case today. It was not more than fifteen years ago that the norm for the water gauge pressure for a flue, duct, or casing system was around seventeen inches.

The early designers of flue and duct considered the insulation application because their water gauge pressure was half of what is required today. The higher the water gauge-number - the bigger the stiffeners.

**INSULATION SYSTEM OF YESTERDAYS WATER GAUGE PRESSURES**

The stiffener sizing of yesterday was based on a much lower water gauge pressure (around 17 inches) and was spaced normally at 24", 36" or 48" spacing. This spacing allowed the insulation to be placed between the stiffeners without having to cut to fit. This typical stiffener spacing was not a coincidence as it matched the average width of a mineral wool board insulation of 24", 36", or 48" wide. Due to the shorter stiffener heights and closer spacing of the stiffeners it was easy to establish guidelines for stiffener heights and insulation design. Here below is one such guideline that I have used and recommended to flue designers for hot systems operating above 350 degrees F:

*Stiffener and Insulation Guideline [See APPENDIX - FIG. (1)]*

- External stiffeners should all be of the same height on any one rectangular surface as required to meet stiffener span designs.
- External stiffener height should all, wherever possible, be no greater than 2" of the minimum insulation thickness up to a maximum stiffener height of 7".
- External stiffener spacing should, wherever possible, be spaced either 24", 36, 48" to accommodate economical insulation applications.
- When the specified insulation thickness is within "2" inches of equaling the total stiffener height than the insulation thickness should be increased to bury the stiffener with at least ½" thick or more.
- When the external stiffeners are spaced six feet or more apart, the insulation should be humped over these stiffeners.
- When the external stiffener height is greater than 7", a 22 gauge inner lagging should be used over the top of the external stiffeners to support the insulation.

Taking that same typical horizontal flue or duct plate as described earlier and using the above Stiffener and Insulation Guidelines [See APPENDIX - FIG. (1)], we can apply determine the proper method of insulation application.

For discussion sake, let us assume that based on yesterdays water gauge of 17", the external stiffener height would be calculated to be no greater then 5"high on 24" centers and the minium insulation thickness calculated to be 5" thick*.

*The insulation thickness was based on using a 8-pound density mineral wool board meeting ASTM C-612 class 4, a surface temperature of 130 deg. F with an ambient air of 80 deg. F and an external wind velocity of 50 feet per minute (fpm) and using an emissivity value of .05 for aluminum lagging.

Per the Stiffener and Insulation Guidelines, the insulation thickness would be increased to 6" so as to bury all the stiffeners. The first layer of 4" would
be laid between the stiffeners and the second 2" thick layer of insulation would be notched to allow for the stiffener flange and placed between the 5" stiffeners. After all the insulation had been applied, then the outer aluminum lagging would be installed over the now flat insulated surface.

**INSULATION SYSTEMS BASED ON TODAY'S WATER GAUGE PRESSURES**

The stiffeners, being designed today on hot flue, duct, SCR or SNCR casing (600 degrees and greater), are quite large and much farther apart. It is very common to find stiffeners 12" or greater. It would be economically impossible to follow the Stiffener and Insulation Guidelines of humping or burying but you could use inner lagging over all the stiffeners. However, this is a very costly and time consuming system. This has opened the door for other insulation systems that would not normally been used for a hot system in years past.

The design parameters for the insulation and lagging systems discussed below will be as follows:

The insulation type will be a 8-pound mineral wool board meeting ASTM C-612 class 4. The outside surface temperature will be 130 deg F with an ambient air of 80 deg F with an external wind velocity of 50 fpm and using an emissivity value of .05 for aluminum lagging. The fasteners shall be spaced to withstand a 30lb per square foot suction or pressure wind loading and all systems are to be considered outdoors.

Designing an Insulation and Lagging System

**Rule 1:** Review the area to be insulated and look at the stiffener size and pattern. Make sure the insulation design will allow the lagging to keep an even flow and pattern (rib direction)

First, plan how to install the outer lagging on the insulated area before considering insulation.

Aesthetics, water drainage (for outdoor application) and foot traffic should also be considered. Designing an insulation system means thinking about lagging.

Analyzing the flow and pattern of the lagging surface based on the choice of insulation design and stiffener pattern and spacing is the first step. The labor and material costs for these choices must then be done. When analyzing labor costs to hump a stiffener versus burying the stiffener, the results are surprising. It is more cost effective to bury stiffeners (even up to 7-inch channels) rather than humping or using an inner support (i.e. 22ga inner lagging) over the top of them.

*Therefore, when your designing flue plate stiffeners (sizing and spacing) take the above into consideration and remember to think about how the flow and pattern of the lagging will go in respect to the stiffeners arrangement.*

Having established a lagging and insulation design (type of insulation, thickness of insulation, and type of lagging), now choose a lagging attachment system that best fits the stiffener arrangement.

**Choosing a Lagging Attachment System**

**Rule 2:** Review carefully your choices of lagging attachments based on the stiffener size and arrangement, and the temperature requirements.

The following describes three of the most commonly used lagging attachment systems used in the power industry today due to the large stiffener arrangements:

**H bar system** - this system is a pre-fabricated and pre-engineered system that is designed and fabricated off site and then installed at the job site or at the flue fabricator's shop. This system was originally designed to be used on low
temperature applications of 450 degrees F and below. The H-bar support system is fabricated very much like continuous gutters and is installed over the outside of the stiffeners. These H-looking steel channels (two C-channels back to back) are attached to the external surface of the stiffeners and form a picture frame which the insulation sits in. The height of the H-bar should equal the thickness of the insulation required. The lagging would then be attached directly to the H-bar frame. Unfortunately, experience has proven that this system is not recommended for hot flues operating over 450 deg F because:

1. The potential heat transfer between the stiffener and the H-bar system to the lagging surface. Adding additional insulation directly to the flue plate prior to installing the H-bar system and adding a high temperature mat between the lagging surface and the H-bar would minimize any heat transfer between the two surfaces.

2. The H-bar system is open at the back closest to the heat. The binder of a mineral wool board insulation burns up at temperatures above 400 degrees F. The open back and picture frame design would allow the insulation to disintegrate over time due to the vibrations normally associated in a flue and duct system. Adding 22 gauge inner lagging to the back of the H-bar system would sandwich the insulation between the outer lagging and the inner lagging and help prevent the insulation from vibrating away. Therefore, when designing flue plate stiffeners (sizing and spacing) take the above into consideration and make sure that there is adequate clearances outside the stiffeners.

II. Pre-Insulated lagging panels - this system is a pre-fabricated and pre-engineered system that is designed, fabricated, and installed at the job site or off site. Unfortunately, experience has proven that this system should be used with caution when the operating temperature is over 450 deg F because of the difficulty in material handling and thermal expansion issues.

Pre-Insulated panels are fabricated from Aluminum lagging which is laid face down on a table in the shop. The insulation pins are welded to the lagging sheet on approximately 12” centers. The insulation material is impaled over the pins. Aluminum foil is then placed over the insulation. A galvanized mesh (generally 2” x 2 5/8”, 16 gauge) is placed over the foil. The mesh keeps the insulation in place and will help prevent the fibers from settling to the bottom. A 2 1/2” square speed clip is placed on the pins which are bent over to hold the panel together. This insulated lagging sheet or panel will then attach to the outside of the stiffeners directly or to a sub system made from angle iron.

Therefore, when designing flue plate stiffeners (sizing and spacing) take the above into consideration and make sure that there is adequate clearances outside the stiffeners.

III. Inner Support System - this system utilizes a support system over the top of the external stiffeners that will support the insulation and lagging. One such method would be to use a 22 gauge inner lagging material and plug weld it to the external stiffeners. Then the insulation and lagging would be installed. The insulation and lagging will be attached to the inner support by a separate support system (pins, clips, Z clips, and or sub-girt). This is a field fabricated system that could be installed either at the job site or at the flue fabricator’s shop. As stated earlier this a very costly and time consuming system to install.

To reduce the cost many people opt to use a 6” x 6” road mesh in lieu of the 22 gauge inner lagging. However, experience has proven that using an open road mesh on temperatures over
450 degrees F is not recommended because the binder of a mineral wool board insulation burns out at temperatures above 400 degrees F. The road mesh would allow the insulation to disintegrate over time due to the vibrations normally associated in a flue and duct system.

Therefore, when designing flue plate stiffeners (sizing and spacing) take the above into consideration and make sure that there is adequate clearances outside the stiffeners.

Please note that the systems described above only scratch the surface of the many different types of lagging and insulation attachment systems available when using a mineral fiber product. Many other types of insulation such as calcium silicates and pearlite along with some of the class V mineral fiber products present their own unique requirements for insulation and lagging system and should be taken into consideration when designing the external stiffeners.

**The Right Design**

As you can see, the insulation and lagging systems described above are directly linked to the stiffener arrangements. Whether you are the designer or installer, the insulation and lagging system should be a prime consideration when designing a hot flue, duct, SCR, or SNCR system. To insulate a hot SCR, SNCR, flue, or duct system that is designed with a high water gauge you will more than likely use a combination of one or more of the above insulation and lagging systems. These insulation and lagging systems should be used with caution as they have very specific thermal expansion, material handling, and clearance issues that must be addressed in the design stage of the contract.

If the external stiffeners were set at a maximum height of 7" then two layers of insulation (4" + 4") could be used to bury the stiffeners. This would allow the lagging to be applied directly to the insulation. This is the preferred method to properly insulate and lag a hot system because:

1. It eliminates the potential heat transfer between the stiffener and the lagging surface.
2. The thermal expansion issues are less because the expansion is taken up in the insulation attachments (pins) and lagging support system (Z clip, stud, sub-girt). These types of attachment systems have less expansion issues then a structurally supported system like the H-bar or panel system.
3. It is the most cost affective (labor and material) application to install.
4. Clearance difficulties are kept to a minimum (Stiffener height + 1" over for the insulation + 1 ½" for the depth of the lagging).
5. Eliminate the problems of binder burnout since the insulation would be sandwiched between the flue plate and the outer lagging.

Therefore, when designing flue plate stiffeners (sizing and spacing) take the above into consideration and try wherever possible to maintain uniformity of stiffener patterns and keep the maximum height of the stiffeners to 7" or less.
CONCLUSIONS

Whether you are the designer or installer, the insulation and lagging system should be a prime consideration when designing a flue, duct, SCR, or SNCR stiffener arrangement. The insulation and lagging design will depend upon the final stiffener design (height and spacing). An average SCR or SNCR system being installed at an existing power plant will cost millions of dollars (including insulation and lagging). Insulation and lagging are key components of either the SCR or SNCR. Large stiffeners are very difficult to insulate and lag economically and have led to insulation and lagging systems being used today that are really designed for low temperature applications. This can lead to hot spots and higher installation costs. A well designed and installed insulation and lagging system will save money and energy at a rate that is essential for an efficient plant operation. So pay attention to your stiffener design specifics especially the water gauge and always take into consideration the insulation and lagging as part of your design parameters.

REFERENCES


APPENDIX

Specific Design Information:

- Duct 8 ft high x 16 ft wide x 3/16" plate
- 24" stiffener spacing
- Temperature of 800 deg F
- Pressure at steady state + 25" $H_2O$
- Pressure at transient state ± 35" $H_2O$
- Flue wall weight ≈ 5" $H_2O$
- Bending Stress = 12,000 PSI
- Allowable Stress Level = 19,000 PSI
- Span = 8 ft = 96 inches

Eq. (1)

Using the above information we will be able to determine the size of the stiffener by using the following formula:

$$\text{Allowable Stress Level} = \frac{\text{Bending Moment}}{\text{Bending Stress}} = \frac{0.0361 \times \text{(design pressure)} \times \text{(stiffener spacing)} \times \left(\text{span}^2\right)}{8} \text{ inches}$$

Eq. (2)

$$\text{Bending Stress} = \frac{\text{Bending Moment}}{Z_{\text{required}}} = \frac{0.0361 \times \text{(transient pressure)} \times \text{(stiffener spacing)} \times \left(\text{span}^2\right)}{8} \text{ PSI}$$
Fig. (1) Stiffener and Insulation Guideline for hot equipment and flues and ducts operating above 350 degrees F.

The figure below is intended to be used as a guide to help the designer of stiffeners and insulation systems.

- External stiffeners should all be of the same height on any one rectangular surface as required to meet stiffener span designs.

- External stiffener height should all, wherever possible, be no greater than 2" of the minimum insulation thickness up to a maximum stiffener height of 7".

- External stiffener spacing should, wherever possible, be spaced either 24", 36, 48" to accommodate economical insulation applications.

- When the specified insulation thickness is within 2" inches of equaling the total stiffener height than the insulation thickness should be increased to bury the stiffener with at least ½" thick or more.

- When the external stiffeners are spaced six feet or more apart, the insulation should be humped over these stiffeners.

- When the external stiffener height is greater than 7", a 22 gauge inner lagging should be used over the top of the external stiffeners to support the insulation.