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Steam Silencer

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ABSTRACT

This project describes how power plants can make their own steam silencers. The silencer is for dry steam based on orifice plates. Its simple design makes it economically viable. The silencer reduces significantly the noise produced by steam discharges where it is needed to relieve pressure. The prototype on which the experiments were made, handles 4 T/h of steam at 160 psig, and it reduced the noise level from 140db to 107db (by 33db). The equipment consists of plates with several orifices in each plate that reduce the pressure in stages.

1. INTRODUCTION

Sound in nature is perceived due to the movement of air layers produced by external pressure waves.

To reduce the noise level of steam relieved to the atmosphere a silencer prototype was designed that distributes the steam flow to several orifices. The sizes of the orifices are based on orifice plate equations.

When an orifice plate is used to reduce the pressure the steam speed in the system is increased as a consequence. If this restriction is too small the steam will choke and the upstream pressure will be increased. This accelerated fluid is undesired in a steam silencer system based on orifice plates because this could mean sonic flow that will provoke even more noise than an atmospheric discharge and high frequency vibrations.

2. STEAM SILENCER

The steam silencer design is based on equations of an orifice plate that has several orifices or holes. These orfice plates are the main characteristic of the system. The plate is called a multi-orifice plate (as seen in figure 1).

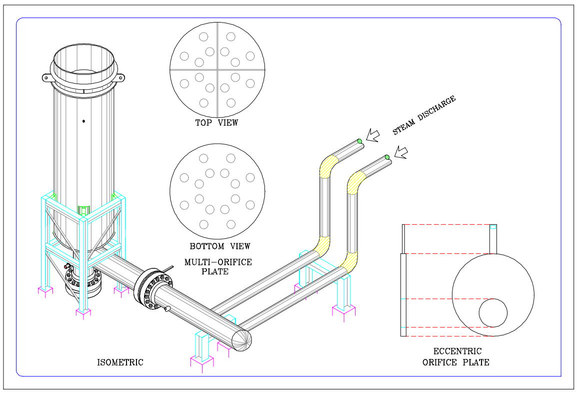

Figure 1: General scheme of a multi-orifice silencer.

Several factors are taken into consideration when designing one of these steam silencers:

The steam expansion process is adiabatic as it flows through an orifice plate.

m_{in} must be equal to m_{out} because this is an open system and there is no mass accumulation.

The flow is assumed to be divided equally to the holes. Because of this, the speed will also be reduced in each hole by equation 8 and this will produce a lower Reynolds number *Re* (less turbulence) according to:

$$\mathrm{Re} = \frac{DV\rho}{\mu} \tag{1}$$

When the steam leaves an orifice plate there is a pressure drop and a change in density ρ. Several state equations may be used but this can be seen easily with the ideal gas equations:

$$Pv = mRT \tag{2}$$

$$\rho = \frac{m}{v} \tag{3}$$

Substituting equation 3 in 2.

$$\therefore P = \rho RT \tag{4}$$

Where P is the pressure, v is the specific volume, m is the mass, R is the gas constant and T is the temperature.

A design error can occur here if a change in density is not taken into account; the flow can be accelerated to sonic flow without noticing.

By having sonic flow an intense and sharp noise is produced. This is more dangerous to the human hearing than the noise produced by a normal steam discharge due to the vortex created in the atmosphere. This kind of noise in high frequency can damage human hearing permanently in some cases.

The external factors that affect the noise level are wind, humidity and temperature. All three factors will affect the capacity of the air to absorb the steam humidity (diffusivity of steam in air), and this way the sound transmission. The bigger the diffusivity the less noise, this can be explained in dry, hot days with wind when these factors help to dissipate the steam into the surrounding air. When steam is relived in cold, wet days with no wind the air is saturated, instead of the steam being absorbed by the air it will tend to move the layers of air (causing noise) until it completely diffuses.

The sound can not be restrained in the silencer because the sound wave is generated out side of the system where steam collides with the atmosphere and moves the air layers.

2.1 DESIGN PROCEDURE

Taking the corrected Darcy's equation with the net expansion factor *Y* from Crane we know that by reducing the diameter of the orifice the pressure drop *ΔP* is increased.

For given conditions of pressure, temperature, flow and density a pressure drop is required but the orifices of the plate are unknown, so the procedure to calculate the orifices' diameter is:

1. Pipe diameter selection.
2. Determine the needed *ΔP*.
3. Calculate the critical velocity *Vc* (sonic flow), where *k*=1.3 for steam (limitation factor of sonic speed):

$$Vc = \sqrt{kRT(777.7)} \tag{6}$$

4. Calculate *Re* in the pipe.
5. With the *Re* calculate the pressure drops in the system, *h*, where *f* is the friction coefficient, *L* is the longitude of the pipe, *D* is the pipe diameter and *g* is the gravity:

$$h = \frac{fLV^2}{2Dg} \tag{7}$$

6. Calculate *k required* that is the sum of all pressure drops, including *ΔP* of the plate.
7. The number of holes is proposed and the flow is divided by that number.
8. An orifice diameter for the holes in the plate is proposed (check if all the holes can be fabricated in the plate).
9. Calculate the orifice relation *β* with the pipe and the proposed orifice diameters.
10. Obtain the flow coefficient *C* for square edge orifices from tables of the orifice plates.
11. Calculate the pressure ratio *rp* and the critical pressure ratio *rc*:

$$rp = \frac{(P_2 - P_1)}{P_1'} \tag{8}$$

$$rc = \frac{P_2'}{P_1'} \tag{9}$$

12. Select *Y* from *C*, *β* and the pressure ratio.
13. Calculate *k of the orifice*:

$$k_{orifice} = \frac{(1-\beta^2)}{(C^2\beta^4)} \tag{10}$$

14. Calculate the area of the orifices if *k required* = *k orifice.*
15. If *k required* is different from *k orifice* go back to step 8.
16. With the corrected Darcy's equation for orifice plates calculate *ΔP* (equation 11) and this must be equal to the needed value in step 2 or very close, to find the exact value go back to step 8 and vary the size.

$$\Delta P = \left(\frac{Q}{YCA}\right)^2 \frac{\rho}{2g*144} \tag{11}$$

Where *Q* is the volumetric flow of the hole and *A* is the area of the same hole.

17. Calculate the speed *V* in the orifices to determine if the sonic speed is reached, *V* < *Vc*:

$$V = \frac{Q}{A} \tag{12}$$

The design premises of the multi-orifice plate are the pressure drop needed, flow, and the pipe diameter that carries the flow, as well as the steam conditions. Iterations for different orifice sizes are made; the number of iterations depends on the convergence according to the pressure drop that we need.

2.2 DESIGN CHARACTERISTICS

Additionally the system must have characteristics of its own to work properly, such as:

- Try to keep low pressure at exit.
- Stay away from sonic flow and have a moderate speed.
- Having the possibility of increasing the number of orifices in the plate.
- Not having an orifice relation bigger than *β*=0.75 or less than *β*=0.20; and a flow coefficient not bigger than *C*=0.78 or less than *C*=0.60. The orifice plate calculations can not go further than these ranges. Because if the orifices are too small the speed will be increased and the system may collapse, on the other hand if the orifices are too big there will be no pressure drop.
- Having a distance after the multi-orifice plate that allows the flow to stabilize after a sudden expansion from 5 to 10 times the diameter of the pipe.
- The length of straight pipe before the plates should be from 10 to 40 times the diameter between pipes. As the orifices relation *β* grows the required pipe length for the optimum plate development grows.
- No concentrical orifices.

2.3 MANUFACTURE

In real life when one of these plates is made, it is very important to realize that the diameters of the orifices must be very precise to have the exact calculated pressure drop. Also the orifices must not be bent for two reasons: the principal is to produce a sudden expansion when the steam leaves the holes, and a secondary reason is to create Karman vortexes that will collide with the ones generated by the nearest holes to lose more energy (in theory), the holes that are not surrounded by holes are close enough to the walls of the pipe to make the flow collide with the walls.

When the pipe is too small and the flow too great no more than one hole can be made in the plate, which means an orifice plate, not a silencer. But when the pipe is too big another problem can appear. If several orifices are made, i.e. the resistance of the plate is diminished and can fail by the stress produce by the steam. This was analyzed by a finite element method for a big steam silencer with stainless steel 316L plates of 66” in diameter ½” thick with a 150 psig steam pressure. The result was that the plates where torn apart by the resistance drop when the orifice plate calculation was made.

The considerations taken for the analysis where fillet welding around the plate to simulate the body of the silencer (pipe) and 16 orifices of 5.89” of diameter. This was solved by incrementing the thickness of the plate or/and by welding reinforcements downstream of the plates (as seen in figure 2) that do not affect the flow.

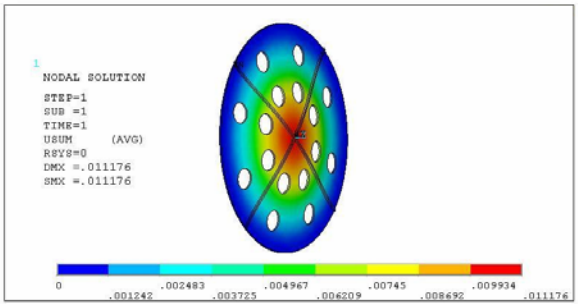

Figure 2: Finite element analysis of a multi-orifice plate.

2.4 PROTOTYPE

The prototype made for the experiments handles 4 T/h of steam at 160 psig, and it reduced the noise from 140db to 107db (by 33db). It has two orifice plates upstream to reduce pressure and two multi-orifice plates to silence downstream.

The whole system was fabricated of carbon steel A-53 gr. B.

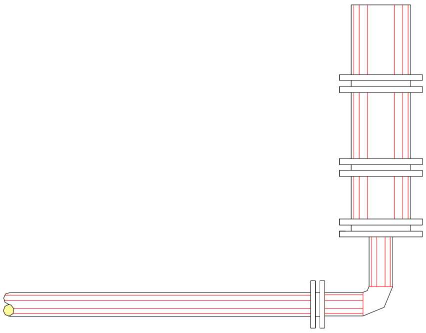

Figure 3: Steam silencer prototype.

The prototype silencer was connected to the exit of a separator pipeline by a line of 2” in the Cerro Prieto Geothermal filed. The well has dry steam and the line was connected perpendicular to the 16” line, if there where to be any water dragging it would be avoided by this.

The mean noise levels from 0.66’ to 16.4’ around the system were of 107 db. Several measurements were taken considering noise, displacement, speed, acceleration and weather conditions.

All the plates worked properly and reduced the pressure exactly as calculated. The first orifice plate reduced the pressure from 160 psig to 70 psig; the second reduced to 35 psig. The next plates (multi-orifice) with 16 holes each caused pressures drops respectively of 25 psig and 10 psig; the last one allows discharging steam at atmospheric pressure.

3. CONCLUSIONS

The paper presented the equations and the process to calculate a steam silencer based on multi-orifice plates and some practical advices to build it.

The results of the experiments proved that the system is practical and doesn’t require expensive technology to build. A system like this can be fabricated in almost any machine shop.

The steam silencer worked correctly in small systems but it hasn’t been proven at a larger scale. Obviously as the steam mass flow increases so will the silencer system. This doesn’t mean linear proportions because none of the equations used is linear and because of the logarithmic equations of sound (equation 13) the amount of sound reductions wouldn’t even be similar.

$$L_p = 20\log_{10}\frac{P}{0.00002}[db] \qquad (13)$$

Up until now the work carried out by the author can not predict the amount of sound reduction.

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