A Model Project

Nick Trout, Lafarge, Mike Porter, P.E., Porter McGuffie Inc., and Andy Winston and Herb Litke, P.E., GE Energy, USA, explain how a baghouse expansion project has improved operation and lowered maintenance and energy costs at Lafarge's Roberta Plant.

Introduction

By expanding an undersized baghouse, the Lafarge Roberta plant in Calera, Alabama was able to reduce daily cleaning cycles by a factor of ten and eliminate frequent bag changes due to excessive abrasion.

In 2002, the Lafarge Roberta plant built a new cement line that included a ten-compartment pulse-jet raw mill/kiln baghouse. The new baghouse turned out to be undersized. Lafarge consulted with GE Energy to correct the situation and improve the line's efficiency.

In production, air volume was 22% over design capacity. The increased air volume pushed the air-to-cloth ratio to the limit, causing a drastic increase in filter bag cleaning cycles and leading to bag failure due to flex fatigue. The increased volume also caused high velocity in the ductwork and in the hoppers, creating abrasion of the filter bags. These conditions led to excessive dust contamination on the clean side that, in turn, led to additional abrasion around the top of the bags. In the first three years of operation, two sets of filter bags (12 880 total) were used.

Analysis showed that the baghouse needed to be expanded. An additional 8% increase in air volume was also needed. Among the factors to be considered were how to redesign all the ductwork to maintain proper velocity and proper air and dust distribution. In addition, changes to the inlet baffling in the baghouse hoppers were required.

The scope of this project included:

- Adding four new modules designed as duplicates of the original ten for commonality of parts.
- Enlarging inlet and outlet plenums to accommodate a 27% air volume increase.
- Inlet plenum redesign to evenly distribute airflow and dust loading based on Computational Fluid Dynamics (CFD) analysis.
- Modifying the inlet ductwork into each module.
- Modifying the hopper baffling.
- Providing 9016 filter bags and cages.
- Installation of all the above.

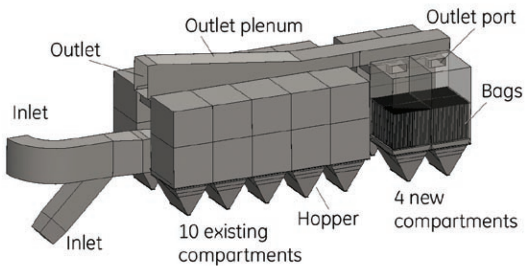

Figure 1. Complete baseline baghouse geometry.

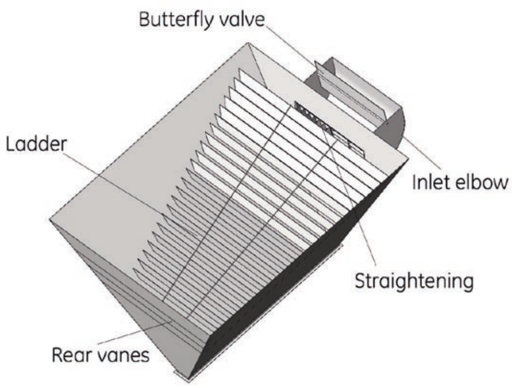

Figure 2. Original hopper geometry.

Table 1. Baghouse operating conditions			
	Original design	Actual operation	New design
Air volume	454 000 acfm (771 350 m³/hr)	580 000 acfm (985 426 m³/hr)	620 000 acfm (1 053 386 m³/hr)
# Compartments	10	10	14
# Filter bags	6440	6440	9016
Air-to-cloth ratio	3.1:1 (0.94 m³/min/m²)	3.96:1 (1.20 m³/min/m²)	3.0:1 (0.91 m³/min/m²)
Can velocity	254 fpm (1.29 m/sec)	324 fpm (1.65 m/sec)	247 fpm (1.25 m/sec)
Compartment inlet velocity	1544 fpm (7.84 m/sec)	1972 fpm (10 m/sec)	Desired - <2000 fpm (10 m/sec)
Inlet plenum velocity	2997 fpm (15.2 m/sec)	3828 fpm (19.45 m/sec)	Desired - <3000 fpm (15.2 m/sec)

Project outline

Each of the 10 original compartments had 644 filter bags, 6.25 in. dia. x 168 in. long (159 mm dia. x 4267 mm), making a total of 6440 bags. Based on the customer's requirements, it was decided that four more compartments would be needed for a total of 9016 filter bags. Before and after operating conditions are detailed in Table 1.

The baghouse contract was awarded to GE Energy in the summer of 2006. It soon became apparent that the project would benefit from a precise design approach using Computational Fluid Dynamics (CFD). For that, GE turned to Porter McGuffie Inc. (PMI), a firm that provides engineering measurement and analysis services.

The purpose of a baghouse is to remove particulate matter from the airstream. It does this in two ways. First, the heavier particles drop out of the air stream when the air expands into the hoppers. Smaller, finer particles are then caught on the outer surfaces of filter bags. The successful operation of a baghouse depends on a relatively uniform distribution of airflow. If high velocity jets or plumes are allowed to form, the larger particles cannot drop out, resulting in abrasive wear on hopper and bag surfaces. This abrasive flow can wear the metal walls of the hoppers and cause dramatically shortened filter bag life. Thus, it is essential that the airflow within a baghouse be as uniform as possible.

CFD allows modelling and analysis of pressure and velocity patterns within a 3D domain that, due to the complex geometry of a baghouse, would be difficult to achieve using traditional scale models.

PMI performed a series of analyses on the Lafarge baghouse design. The analysis of the existing geometry was used to determine the flow patterns within the current baghouse and to determine areas where flow improvements could be achieved.

Figure 1 illustrates the overall geometry of the model including plenum, hopper entrance ducts and hoppers. The bags were simulated using a porous media approximation occupying the same geometric volume. The outlet plenum was modelled using the actual geometry.

The inlets were defined as mass flow boundary conditions, with a total flow of 620 000 acfm (1 053 386 m³/hr). The mass flow per inlet was determined using a ratio of the inlet area of the individual inlets to the total area of the combined inlets. The outlet was treated as a pressure outlet at atmospheric pressure. The bag porous medium was defined to provide a 1.5 in. (38 mm) w.c. pressure drop at nominal flow conditions. The working fluid was defined as air and treated as an ideal gas.

The original hopper (illustrated in Figure 2) consisted of an inlet elbow containing a butterfly valve. The valve is used to control the flow into the hopper, primarily for servicing purposes. At the end of the elbow, there is a set of flow-straightening vanes that is intended to direct the flow to the proper regions in the open area of the hopper. In that area, there is a set of ladder vanes to redirect the flow into the bags. As can be seen from Figure 2, the ladder vanes lie along a line that is at approximately a 20° angle to the incoming flow. Additionally, individual vanes are canted to the incoming flow to assist in distributing it evenly into the bags. Finally, there is a set of vanes at the rear of the hopper to prevent a large amount of flow from impinging on the rear wall and being directed up at this location.

The analysis of the original geometry showed that there was a strong misdistribution of airflow into the hoppers from the inlet plenum. Figure 3 illustrates the hopper numbering scheme used to identify the individual hoppers.

Table 2 shows the difference between mass flow rate into each hopper and the mean mass flow rate.

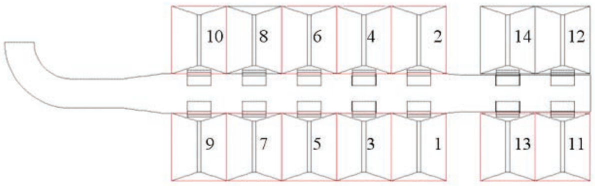

Figure 3. Hopper layout.

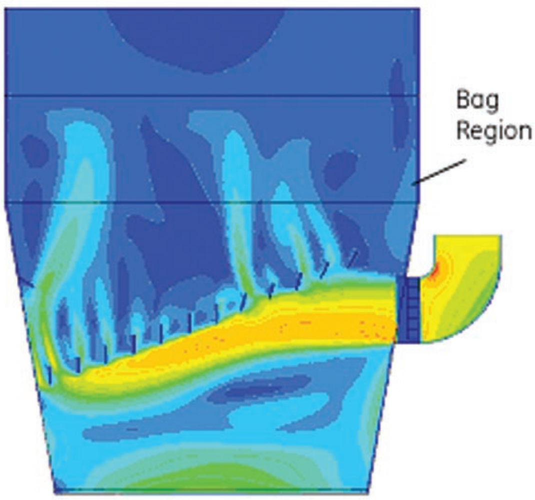

Figure 4. Velocity profile within original hoppers.

Table 2. Comparison of mass flow rates at hopper locations

Location	% difference from mean
1	3.55
2	0.090
3	-1.35
4	-4.68
5	-3.65
6	-6.68
7	-3.90
8	-6.44
9	-3.65
10	-7.43
11	17.32
12	15.49
13	1.78
14	-1.26

The table shows a variance of -7.4% to 17.3% from the mean mass flow rate. Ideally, the difference from the mean should be as close to zero as possible. High variability in airflow results in some hoppers being highly loaded while others are under-used. The highest mass flow rates occur at the last two hoppers attached to the inlet plenum, 11 and 12. The CFD results indicate that high stagnation pressures due to the slowing of the bulk flow occur at the end of the plenum. Since the flow rate through the hopper is dependent on the static pressure occurring at the inlet to the hopper, these high stagnation pressures lead to higher flow through the end hoppers.

The flow results from the original hopper analysis indicated that there were several areas where improvements could be achieved. Figure 4 illustrates the velocity profiles along the centreline of a typical hopper.

As can be seen, only the front four and last three vanes turn the flow toward the bag region. The result of the misdistributed flow is localised high velocities, particulate entrainment, flow impacting the bags on the front and rear of the hopper, and low velocities impacting the bags in the centre. With this flow pattern, high wear rates at the front and rear of the hopper and significantly reduced wear rates in the centre would be expected. Additionally, the high velocity flow impacting the side of the hopper opposite the entrance resulted in significant hopper wall erosion.

To improve the flow pattern, CFD was used to examine the effects of changes to the baghouse geometry. The geometry of the inlet turning vane and the layout of the ladder vanes can significantly affect the flow distribution into the bags. It was determined that the best results were achieved by removing half of the ladder vanes and including a turning vane in the inlet elbow. Several types of turning vanes were considered, including horizontal, angled and curved. The horizontal vane and a vane angled at 10° down from horizontal provided the best distribution of flow into the bags.

After a final design layout had been determined through 2D models, a 3D model of the geometry was constructed to validate the flow results before the new geometry was incorporated into the full baghouse model. Figure 5 shows the velocity distributions for the selected final geometry; in this case, half of the ladder vanes were removed and a horizontal turning vane was placed in the inlet elbow.

Here there is greatly increased flow through the centre ladder vanes due to the flow on top of the elbow vane. Also, the flow through the rear vanes has been considerably reduced compared to the original analysis.

To improve the flow distribution through the inlet plenum, steps were taken to reduce the stagnation that was occurring at the end of the plenum. To accomplish this, the longitudinal narrowing of the passage over hoppers 11, 12, 13 and 14 was removed. Additionally, turning elbows were placed over the entrances to hoppers 11 and 12 and a flow splitter was used to divert the flow to the elbows. Figure 6 shows the modified inlet plenum geometry.

Figures 7 and 8 show the velocity and pressure results of this analysis within the inlet plenum. The bulk velocity is more even with the modified plenum design. The more uniform bulk velocity within the inlet plenum also results in reduced stagnation pressures for the last hoppers.

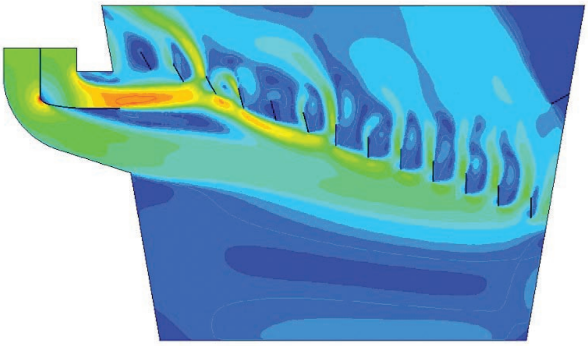

Figure 5. Redesigned flow distribution.

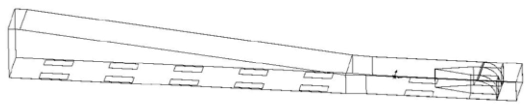

Figure 6. Modified inlet plenum geometry.

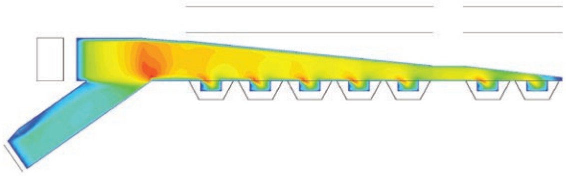

Figure 7. Inlet plenum velocities for modified plenum design.

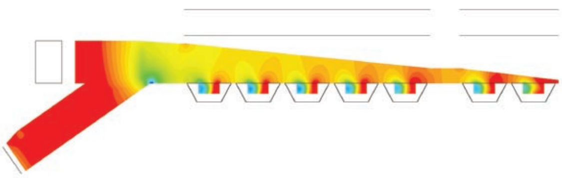

Figure 8. Inlet plenum pressures for modified plenum design.

Figure 9. Fibreglass filter laminated with high efficiency ePTFE membrane.

Based on the results from PMI's CFD analysis, GE Energy incorporated changes into its baghouse design. The revised design allowed the use of filter bags made of high efficiency ePTFE (expanded Politetrafluoroethylene) membrane laminated to 22 oz/yd^2 (746 g/m^2) woven fibreglass (Figure 9) without concerns for short filter bag life due to inlet abrasion. This filtration fabric has performed best in kiln systems and is in use in over 65% of US kiln baghouses. Other fabrics have been tried with limited success; none have approached the performance of the membrane laminated fibreglass filter bags.

Some of the benefits include higher airflows, lower differential pressure, lower emission levels, and longer filter life than any other media available today. The micro porous ePTFE membrane keeps the dust on the surface of the filters, making it difficult for it to penetrate the interstices of the backing media. This prevents internal abrasion of the glass fibres. These filters also require less energy and less frequent cleaning, thus reducing wear and extending their service life.

Adding the four new compartments increased the filtration area, thus lowering the air-to-cloth ratio to well within design best practices. The expected result from this change was to handle the capacity requirements and to greatly reduce the number of cleaning cycles per day, lowering the chance of filter bags failing prematurely. Enlarging the inlet and outlet plenums helped to reduce the velocities into the target range. Incorporating the other changes in the inlet plenum derived from the CFD analysis promised more even air flow and dust distribution, allowing each compartment to share the workload equally.

In addition, GE Energy worked with Lafarge on a new control and monitoring logic for the baghouse. The control logic helps to maintain a consistent differential pressure across the baghouse while minimising cleaning cycles.

Conclusion

The project was completed in early 2007. After two years of operation, the system has surpassed expectations. The differential pressure across the baghouse has been maintained at the same low level throughout the two-year period. The number of cleaning cycles per day is below 25, one-tenth the level prior to the expansion. Before the addition of the four new compartments on the kiln/mill baghouse, the system required constant and expensive maintenance. Changing failed filter bags was a weekly occurrence. Since the completion of the project, the only filter bags removed have been for testing.

"Overall, this was a very successful project for Lafarge," said Project Manager Nick Trout. "The results exceeded our expectations in terms of providing an excellent quality product that continues to perform within the operating parameters set forth in the justification for the project. We have gone from spending over US$40 000 per month on baghouse repairs to no cost at all. In addition, we are using a lot less compressed air to clean the filter bags and we have reduced the static pressure on the fan by over 4 in. (10 mm) w.c., which has enabled us to realise substantial energy savings. I would recommend using GE Energy and Porter McGuffie Inc. for any baghouse work."