BENEFITS OF HIGH TEMPERATURE MEMBRANE FILTER MEDIA IN THE TUSCALOOSA STEEL CORPORATION BAGHOUSE

James E. Yerkes[1], Joseph T. Renfroe[1], William M. Hosmer[1] , Frank Fereday[2], Peter Kleine-Moellhoff[2], Stephen M. Sanders[2]

[1]Tuscaloosa Steel Corporation, Tuscaloosa, Alabama, USA

[2]W. L. Gore & Associates, Inc., Elkton, Maryland, USA

SUMMARY

Tuscaloosa Steel Corporation (TSC - a subsidiary of British Steel, plc) began operation of an Electric Arc Furnace Meltshop in October, 1996. The installed air pollution control (APC) system is composed of a 2.4 million Am^3/h (1.4mm ACFM) reverse air baghouse and associated fume collection equipment and ductwork. Fume is collected directly from the electric arc furnace shells, ladle metallurgy furnace hood, meltshop scavenger duct and roof canopies located above the electric arc furnaces and caster turret. Due to frequent high temperature conditions at the baghouse, the APC system operation had to be modified to protect the conventional low temperature media filter bags originally installed. The modification required operating the baghouse at higher than original design airflow rates, at times sacrificing suction pressure, to support higher levels of dilution air. With the new high temperature membrane filter media, required dilution air is reduced and optimal baghouse suction pressure is consistently maintained, reducing fugitive emissions. The combination of less dilution air and lower pressure drop across the bags reduces overall APC system power consumption. The high temperature membrane filter material shows better resistance to light spark damage, reducing the frequency of bag repairs and changes and maintenance costs. This paper describes the performance of this filter media in an Electric Arc Furnace Meltshop application focusing on the economic implications of this performance.

1. MELT SHOP EQUIPMENT

The heart of the Tuscaloosa Steel meltshop is a Twin Shell DC electric arc furnace designed and built by MAN GHH. Each shell is 7.1 meters in diameter with a single 710 mm (28 inch) electrode serving both shells. The furnaces feature eccentric bottom tapping (135 metric tons per heat) with a 30 metric ton liquid heel remaining in the furnace. In addition to the heat supplied by the two 58 MVA parallel transformers (116 MVA total), oxy - fuel burners are used at the door and in the EBT area. Furnace power input averages 84 MW during the melting period and 70 MW during refining.

A water cooled lance with carbon foamer and supersonic and up to 30 kg/min of carbon. The furnaces can run on 100% scrap; however, TSC's goal is to use a substantial amount of DRI (up to 50% DRI) to achieve product quality. The DRI pellets (from the Tuscaloosa Steel plant located in Mobile, Alabama) are added both with the scrap bucket and continuously via conveyors so that each heat is produced from a single bucket charge. Tap to tap time averages less than 60 minutes.

The melt shop also includes a 20.5 MVA capacity ladle metallurgy furnace supplied by MAN GHH. Liquid steel from the melt shop goes to a single stand caster designed and built by SMS Concast. Annual plant output is designed to be about 720,000 prime metric tons per year of coiled, cut to length, and discrete carbon steel plate.

2. AIR POLLUTION CONTROL EQUIPMENT

Like most electric arc furnace shop systems the higher temperature gas from the furnace primary system mixes with cooler gas drawn through the secondary systems. At Tuscaloosa the primary gas drawn through the Direct Evacuation Control (DEC) system mixes with cooler gases from the ladle metallurgy furnace, the "elephant house" canopy hoods, the caster turret canopy and from a scavenger duct drawing from the very top of the meltshop building. Table 1 summarizes the original system design.

Tab. 1: System Conditions with One Shell Melting and One Shell Preheating Original Design Conditions

	Mass Flow (kg/min)	Temp. (°C)	Volume (Am^3/h)
Ladle Furnace	2,268	121	152,790
Caster Tundish Canopy	4,536	54	253,932
Elephant House Canopy - - Melting Furnace	9,072	54	507,864
Elephant House Canopy - - Preheating Furnace	9,072	54	507,864
Scavenger Duct	5,897	54	330,112
Combined Volume from Secondary Sources	30,845	60	1,756,006
Water Cooled Duct Exit	2,948	593	436,419
Cooling Air at Baghouse Inlet	2,948	32	153,866
Baghouse Inlet	36,741	104	2,388,749

The secondary sources combine into one 5.3 meter diameter header and join with the primary gas coming from a 2.9 meter diameter duct. The primary and secondary gas systems meet less than 30 meters from the baghouse inlet. An Amerex Industries baghouse collects all primary and secondary meltshop fume.
Table 2 shows the original baghouse dimension, table 3 summarizes the main fan specifications.

Tab. 2: Baghouse Dimensioning - Original Design Condition

Baghouse flow	Am^3/h	2,400,000
Cleaning Method		Reverse Air
Baghouse Inlet Temp	°C	104
Compartments		16
Bags/compartment		348
Bag diameter	mm	305
Bag length	m	11.0
Gross filter area	m^2	56,646
Net filter area	m^2	53,105
Gross air/cloth ratio	m/min	0.70
Compartments off line for cleaning		1
Net air/cloth ratio (with reverse air)	m/min	0.79
Filter bag description:		
Material		Seamless Polyester
Initial Permeability @ 20 mm w.g.	m_/m_min	0 to 17
Maximum Temperature	°C	135
Weight	g/m_	355

Tab. 3: Baghouse Main Fan Specifications

Fan Location		Baghouse Outl
Number of Fans		4 incl. 1 spare
Gas Volume	Am^3/h	800,000
Design Operating Temperature	°C	93
Design Fan Static Pressure	mm wg	610
Design Operating Power	kW	1,641
Motor Size	kW	2,610

3. INITIAL OPERATING RESULTS

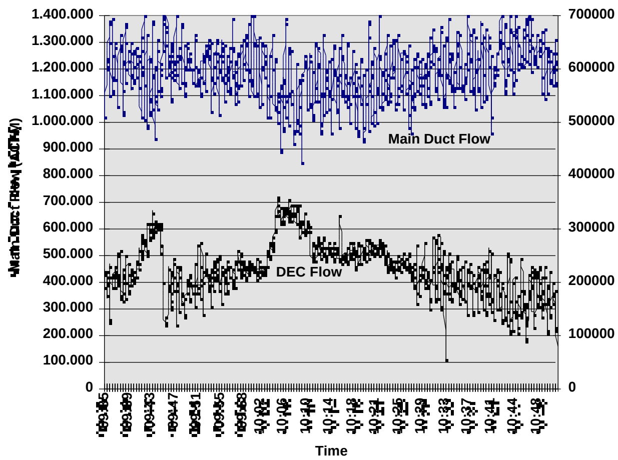
Burn holes in the bottom area of the bags proved to be a problem from the outset of meltshop operations and bag failures started almost immediately. Most disturbingly, with a three fan operation the system could not adequately capture fume from the meltshop equipment, with the ladle furnace proving to be especially difficult to ventilate. Table 4 compares design and field results.

The table shows that the baghouse operated at nearly the design volume but well below the expected temperature. Too much of the gas came from the low dust concentration sources (the caster area and from the overhead canopies) while the high dust generation points (ladle furnace and the furnace shells) were under ventilated. The field data do not indicate how much of the DEC flow came from the furnace shells and how much was bleed air at the gaps, but it is apparent that the gas volume at the exit of the water cooled ductwork includes much more tempering air than originally planned since the gas temperature is far below the original aim of 593 °C. Additional tempering air tends to break the suction in the DEC duct with a corresponding drop in fume capture at the furnace shells. The flow of 507,000 Am3/h at 396 °C was not sufficient to ventilate the furnace shells.

In order to avoid higher baghouse inlet temperature and high pressure drop across the filter bags due to higher dust load from the DEC system, TSC had to increase the amount of dilution air coming into the system during the most intense part of the heat when fume generation was at the maximum. The control system automatically opens the canopy dampers to protect the original low temperature filter bags from high temperature.

Figure 1 taken from the August 14 1997 field data shows how DEC volume drops as the flow from the secondary sources (low dust load) increases.

Fig. 1: Tuscaloosa Steel Corporation, Baghouse Draft System Analysis, August 14, 1997



4. CHANGE TO FOUR FAN OPERATION

Since the three fan operation did not adequately prevent meltshop emissions, Tuscaloosa Steel started the fourth fan that had been intended for use as a spare. That increased the baghouse gas flow and allowed TSC to improve ladle furnace and DEC gas flow. Table 5 compares the measured gas flow under three and four fan conditions:

Tab. 4: Comparison of Design Data and Field Results of August 14, 1997 Conditions

One Shell in Melting and One Shell in Preheating						
	Design Mass Flow (kg/min)	Design Temp. (°C)	Design Volume (Am^3/h)	Measured Mass Flow (kg/min)	Measured Temp. (°C)	Measured Volume (Am^3/h)
Ladle Furnace	2,268	121	152,790	1,837	71	107,419
Caster Turret Canopy	4,536	54	253,932	6,427	46	348,516
Combined Volume from Secondary Sources	30,845	60	1,756,006	32,857	46	1,781,636
DEC Exit	2,948	593	436,419	4,460	396	506,808
Baghouse Inlet	36,741	104	2,388,749	37,317	88	2,288,444

At the higher gas flow, spark carry over to the baghouse became a serious problem with an average of 18 polyester bags showing burn holes every day. The baghouse maintenance crews had to repair these holes and still replaced an average of 65 bags per week. In a twenty week period from late March to mid August 1998 the maintenance people replaced 1313 bags, with the rate of replacement increasing by 45 % over that period.

Unfortunately at the higher gas flows (both total and DEC), the baghouse was still not able to avoid periodic high inlet temperatures. The control system program maintains baghouse entry suction pressure by positioning the canopy dampers above the furnace shells. The dampers close to increase pressure and open to reduce pressure. To protect the bags from over temperature, an override system was developed to open the canopy dampers as the baghouse inlet gas temperature reaches 116 °C. Even with the higher flows generated by a four fan operation, the system continued to swing between pressure and temperature control modes thus causing inconsistent fume evacuation through the primary fume system.

Tab. 5: Measured Gas Flow under three and four Fan Operation

Test Date	Number of Fans	Average Gas Flow (Am^3/h)	Average Temperature (°C)
August 14, 1997	3	2,127,005	68
May 8, 1998	4	2,637,429	80
September 10, 1998	4	2,889,871	60
October 9, 1998	4	2,956,588	63

Unlike a kiln or coal fired boiler, electric arc furnace operations are a highly transient process. Schmitt, et al (1) have reported an increase in dust generation during slag foaming, and Jones (2) has reported that offgas flow rates can increase by a factor of 1.5 and heat load can increase by as much as a factor of 2.5 for high slag foaming rates.

Table 6 projects system performance with a four fan operation. The DEC flow during the peak condition represents the flow at one standard deviation above the adjusted mean of the August 14, 1997 data. Baghouse flow is based on the measured gas flow during the September 1998 field test.

Tab. 6: Projected System Performance with a four Fan Operation

Filter Media Furnace Mode		Polyester Peak Melting	Polyester Normal Melting
Baghouse flow	Am_/h	2,889,871	2,889,871
Baghouse Inlet Temp	°C	125	82
Maximum bag temperature	°C	135	135
DEC system volume	Am_/h	722,143	446,315
DEC gas temperature	°C	599	381
DEC system mass flow	kg/min	4,926	4,055
Main Duct Volume	Am_/h	2,167,728	2,443,557
Main Duct Temperature	°C	60	54

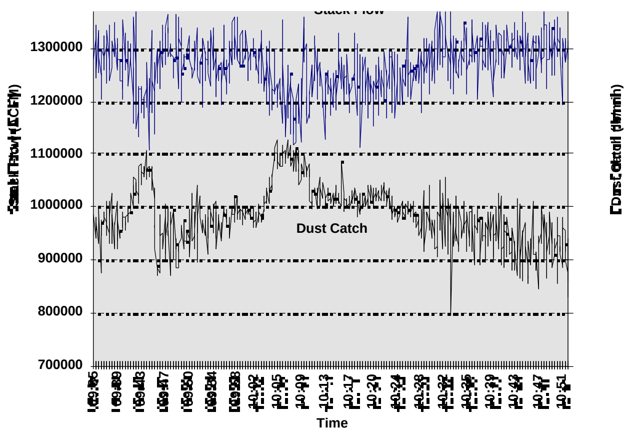
The table shows how the transient nature of the electric furnace process, even at a very high baghouse flow rate, can increase the baghouse inlet temperature to the limit of polyester bags. Any upset in DEC flow as may occur during a scrap cave in or high slag foaming would put the baghouse inlet temperature over the 135 °C limit of polyester bags.

Haissig and Gebert (3) report that dust pick up from the primary system ranges from 7.5 kg to 20 kg/ton of liquid steel while the dust catch in secondary systems ranges from 0.5 to 3.5 kg/ton of liquid steel.

Figure 2 is based field data gathered on August 14, 1997 weighted on the basis of 14 kg/ton from the primary system and 2.5 kg/ton from the secondary system.
Figure 2 shows the distinctly inverse relationship between dust pick up from the melt shop and baghouse stack volume. The higher the stack volume – the lower the dust catch. This shows the negative effect of opening the canopy dampers too much.

Fig. 2: Relationship between Dust Pickup from the Melt Shop and Stack Gasflow

By mid 1998 TSC was operating four fans at full motor load of 2600 kW, was repairing an average of 56 bags per



shop primary evacuation since the suction pressure at the end of the water cooled duct work would drop from 225 mm w.g. to as low as 100 mm w.g. when the system went into the temperature control mode. That drop in DEC suction corresponds to a 33% decrease in primary gas flow. Varying furnace draft made consistent furnace melting conditions more difficult to achieve. The original complement of filter bags needed to be replaced in less than two years of operating time. With this background Tuscaloosa Steel sought a better filter media allowing a cost effective solution to the problems of melt shop emissions, high power consumption and high bag maintenance costs. One solution TSC investigated and chose was the high temperature membrane fabric filter bag supplied by W. L. Gore and Associates.

5. DIFFERENCE BETWEEN CONVENTIONAL AND MEMBRANE FABRIC FILTRATION TECHNOLOGIES

When fabric filter dust collectors became a viable technology years ago, the available fabric filter media included wool and cottons, then progressed to the synthetics such as polyester, aramid polymers fibers, and glass fibers. This method of filtration was and is referred to as conventional depth filtration. Twenty-four (24) years ago, W. L. Gore & Associates, Inc. (Gore) introduced expanded polytetrafluoroethylene (ePTFE) membrane surface filtration, offering significant advantages over conventional depth filtration.

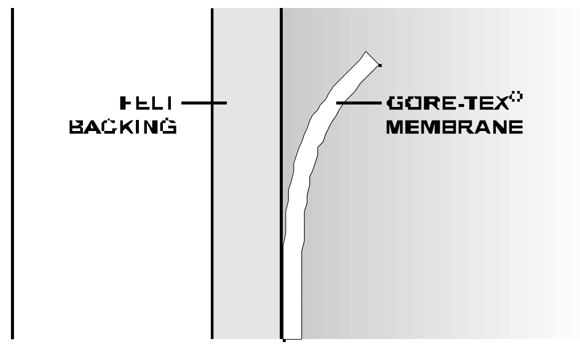
Conventional Depth Filtration

The nature of conventional (or depth) filtration is to build a "primary" layer of dust cake in and on the media. Actual filtration can then begin on this primary dust cake. Without the primary dust cake, conventional (non-membrane) filter media is only 30-70% efficient. This necessary build-up of primary dust cake produces higher pressure drops. To maintain an acceptable static pressure, the secondary dust cake must be removed on a regular, sometimes continuous, basis. But this excessive cleaning can upset the primary dust cake and emissions are high until the primary dust cake is built up again. Add any moisture or condensed humidity to the system and the conventional filter bag may have a dust cake that is impossible to clean. This reduces airflow and production, while maintenance and downtime, increase. Moisture aside, the primary dust cake becomes dense over a period of time, decreasing the air flow permeability of the bag.

Membrane Surface Filtration

Membrane surface filtration began when Bob Gore (founder Wilbert Gore's son, and now president of W. L. Gore & Associates, Inc.) discovered that PTFE could be expanded and applied to conventional filter media (see Figure 3). The benefits to industrial filtration applications were numerous, and began at a microscopic level. To explain, the expanded PTFE membrane structure includes layers and layers of nodes and fibrils. Even submicron sized particles must negotiate a "tortured path" to penetrate through the membrane, so the vast majority of particles are trapped at the surface where they are then easily removed.

Fig. 3: Lamination of ePTFE to a Filter Media



In essence, the membrane replaced the need for a primary dust cake and provided consumers remarkable benefits. The expanded PTFE (polytetrafluoroethylene, commonly known as TEFLONâ) material is smooth and slick -- allowing for extremely efficient cleaning in filtration applications -- the dust "slides off" the media, reducing pressure drops, maintenance and downtime, etc. (see Figures 4 and 5). In addition, the GORE-TEXâ membrane is breathable and waterproof, allowing airflow through the media while protecting the backing material.

Fig. 4: Membrane Surface Filtration

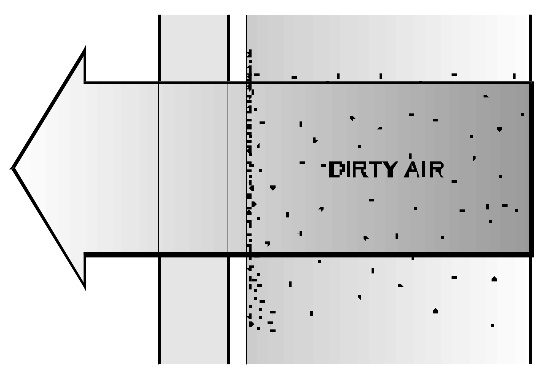
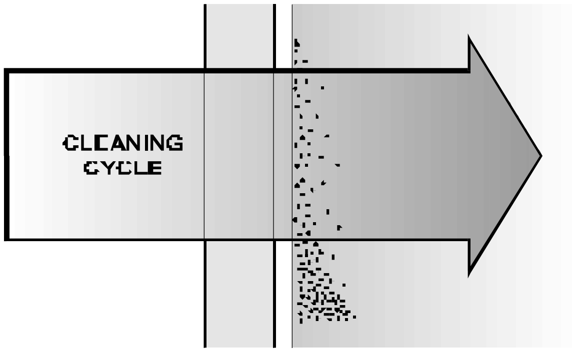


Fig. 5: Surface Filtration Cleaning Cycle



More significantly, the GORE-TEXâ membrane filters are engineered to filter from ultrafine and fluid to sticky, moist, and abrasive dusts.
The GORE-TEXâ ePTFE membrane can be thought of as a permanent, factory-applied, primary dust cake. The ePTFE membrane, a non-stick and chemically-inert substance, enhances the release of the secondary dust cake during the cleaning cycle. Since no internal dust cake ever develops, the permeability recovers to almost original levels after each cleaning cycle with no gradual decrease in permeability over time. In addition, there are no initial emissions during start-up of the system, as with conventional media, before the filter surface becomes seasoned.

6. BENEFITS OF MEMBRANE FILTER MEDIA

Earlier work by Person (4) explained the relatively high pressure drop characteristic of conventional woven fiberglass material. While aramid material in shaker cleaning applications shows lower filter resistance than woven fiberglass material, the work reported by Eriksen (5) shows GORE-TEXâ membrane/fiberglass filter media has substantially lower filter drag than non membrane filter media. The operating experience showed that Tuscaloosa Steel was not able to maintain adequate equipment ventilation at 150 mm w.g. suction at the baghouse inlet.

Previous work by G. D. Hall, et al (6) showed the improved performance of GORE-TEXâ membrane filter bags when compared to the results seen with conventional woven and felted synthetic filter media (4)
Table 7 projects performance improvements made possible by high temperature membrane filter bags at Tuscaloosa Steel. The temperature and flow values for the High Temperature Membrane column are based upon thermodynamic calculations, using a model developed from TSC data, under revised operating conditions:

Tab. 7: Performance Improvements by High Temperature Membrane Filter Bags

Baghouse System			
Filter Media		High Temp.	Polyester
Baghouse Inlet Suction	mm wg	-225	-150
Furnace Mode		melting	melting
Baghouse flow	Am^3/h	2,601,484	3,060,569
Baghouse Inlet Temp	°C	143	91
Compartments		16	16
Bags/compartment		348	348
Bag diameter	mm	292	305
Bag length	m	11	11
Gross air/cloth ratio	m/min	0.77	0.91
Net air/cloth ratio (with rev air)	m/min	0.87	1.01
Primary Systems			
DEC system volume	Am3/h	722,143	446,314
DEC gas temperature	°C	599	381
Secondary Systems			
Main Duct Volume	Am_/h	1,879,341	2,614,255
Main Duct Temperature	°C	68	64

Less Dilution Air

By taking advantage of the higher temperature capacity of GORE-TEXâ membrane/fiberglass filter media the amount of dilution air can be reduced substantially. Even at a higher DEC volume the GORE-TEXâ membrane/ fiberglass bags are far below their 260 °C limit. In order to avoid high temperature damage to the polyester material the baghouse had to operate periodically at significantly higher than original design airflow rates, sacrificing suction pressure, to attain the higher levels of dilution air. With the new high temperature membrane filter media, required dilution air is reduced while maintaining consistent baghouse inlet pressure and furnace draft, thereby reducing fugitive emissions.

Higher DEC volume

Since the baghouse inlet temperature is no longer limited to 135 °C and pressure drop across the filter bags is lower with membrane bags, TSC is able to operate with a consistently higher DEC gas flow. This improves the shop environment since each cubic meter of DEC gas carries from 30 to 40 times more dust than a cubic meter of secondary gas. Since gas flow from the furnace is much more stable, a higher portion of the CO can burn in the furnace. This contributes to more uniform scrap melting in the upper portion of the furnace and smaller scrap pieces reaching the arc flare which helps to reduce scrap cave ins. Since DEC volume is more stable, the chances for an explosion in the DEC system is significantly reduced.

Lower Power Consumption and Improved Maintenance Capability

Since there is no need to oscillate control between pressure and temperature modes (relatively low flow and relatively high flow) and because of the lower filter drag with the high temperature membrane filter bags, it is anticipated that TSC will realize substantial power savings after the in 1999. With the return to a three fan and one fan idle operation, a planned maintenance regimen to the idle fan will again be implemented improving overall fan reliability.

Longer Effective Bag Life and Improved Resistance to Spark Damage

With proper inspection and maintenance, GORE-TEXâ membrane/acid resistant fiberglass fabric filter bags operate effectively for many years. Effective bag life is projected at five years and in most cases the GORE-TEXâ membrane bags will last much longer than five years. In less than two years time the original bags needed to be replaced. TSC had to consistently repair or replace polyester bags because of spark damage and bleed through. In five month alone TSC replaced 1313 bags and repaired 1120 bags. Since TSC installed the first GORE-TEXâ high temperature membrane bags over five months ago, not one bag has failed.

Improved Resistance to Moisture Upsets

Leaks from water cooled components are very common in electric arc furnace systems. In the past water leaks that carried over to the baghouse created a heavy dust cake on the conventional polyester bags in the compartments near the baghouse inlet. Once coated the reverse air cleaning system could not remove the heavy dust cake. Since the membrane is hydrophobic, the membrane bags are able to recover from water upsets and TSC has not seen the heavy dust cake conditions since the GORE membrane bags were installed.

Lower Outlet Emissions

Due to the improved collection efficiency of the membrane bags the stack discharge opacity has dropped by about 2% to virtually a zero reading.

References

(1) Schmitt, R. J., Kusik, C.L., O'Neil, R, Cowx, P. M., Schade, C. T., "Mimimizing Electric Arc Furnace Dust Formation", Electric Furnace Conference Proceedings, Volume 55, 1997

(2) Jones, J.A.T., "New Steel Melting Technologies", Iron and Steelmaker, Volume 23, July 1996

(3) Haissig, M., Gebert, W., "The Revamp to a Fuchs Shaft Furnace at Von Roll", Electric Furnace Conference Proceedings, Volume 55, 1997

(4) Person, R.A. ”Current Status of Ferroalloy Emission Controls”, Electric Furnace Conference Proceeding, Volume 33, 1975

(5) Eriksen, E., ”Economy and Development in Ferroalloy Dust Collection”, Electric Furnace Conference Proceedings, Volume 43, Atlanta, 1985

(6) Hall G. D, Prater B. E, Taylor D., Topham T., “A Study of Electric Steelplant Baghouse Filtration”, British Steel Corporation, Swinden Laboratories, Rotherdam, Scotland, U.K., May 1991