IMPROVING THE EFFICIENCY OF AN EXISTING BOF MELT SHOP EMISSION CONTROL SYSTEM

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ABSTRACT

This paper discusses the extensive developments that were carried out in order to improve the effectiveness of the primary gas cleaning system at Gulf States Steel melt shop in Gadsden, Alabama. A preliminary analysis was conducted in order to evaluate the performance of the existing Basic Oxygen Furnace (BOF) fume control system and to assess its limitations. Based on the initial study, detailed design was carried out for the spray chamber and the electrostatic precipitator (ESP) modifications. The ESP expansion required major modifications to the existing duct r ig. In order to ensure desired air flow distribution th..ugh the existing and the new units an air-based fluid dynamic model was constructed to predict the gas flow distribution.

INTRODUCTION

The Gadsden meltshop originally owned by Republic Steel Corporation was started up in 1964, replacing an eight furnace open hearth shop. The facility was purchased from Republic Steel by LTV before being owned by Gulf States Steel. The Gulf States Steel BOF meltshop is equipped with two 175 ton vessels, a ladle metallurgical station and a single strand continuous caster.

The basic components of the emission control system originally installed for the GSS full combustion BOF vessels include 45° inclined water cooled fume hoods over the vessels, a cascade-type water evaporation chamber to condition the off-gas, insulated ducts leading to two double-chamber four field dry electrostatic precipitators, with three fans rated at 240,000 acfm at 500°F and 15 in. w.g. static pressure. The original evaporation chamber side walls were replaced by dry type water cooled panels in 1979.

An extensive field survey was conducted with the objective of establishing performance parameters for the existing off-gas handling system. The key findings of the field survey a mmarized below:

- Evaporation of water in the spray chamber was incomplete due to large droplet diameters created with direct pressure spray nozzles. As a result of this poor evaporation:
  - wet dust particles caused build up in the ducts, and contributed to plugging of the precipitator inlet/outlet perforated plates, and;
  - the off-gas moisture content was lower than desired levels, which adversely affected the precipitator cleaning efficiency due to high dust resistivity.
- the precipitators were performing inadequately, in particular during start/end of the oxygen blow and reblows.

This article summarizes the activities associated with design improvements to the evaporation chamber and the electrostatic precipitator system.

OFF-GAS CONDITIONS

Initial off-gas system conditions during various phases of the melting cycle are shown in Figure 1. The low flow condition of about 100,000 acfm at 120°F represents the gas conditions during the tapping cycle and furnace idle mode. High suction (about 600,000 acfm) starts prior to charging hot metal and continues until the oxygen blowing cycle ends. The off-gas temperature during the blowing cycle varies from about 200°F at the beginning of the blow, reaches about 600°F during the peak of the blow and then reduces back to about 200°F at the end of the cycle. Typically, the oxygen blow lasts between 18 to 22 minutes with a continuous change in the flue gas and dust characteristics during the entire cycle. The water spray rate for off-gas conditioning varied between 300 and 700 gpm during the oxygen blow. The off-gas dust loading was about 5-6 gr/acf.

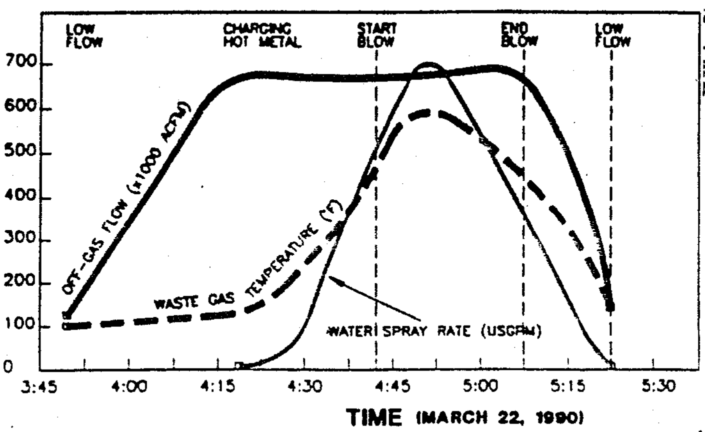

Figure 1. Off-Gas System Conditions

SPRAY SYSTEM MODIFICATIONS

The original evaporation chamber was equipped with six banks of direct pressure nozzles to condition the gas from an inlet temperature of 2,200°F to an outlet temperature of 550°F for entry into the gas main and electrostatic precipitator. Spray system consumption was about 700 gpm at an operating pressure of 300 psig. Water for the spray system and panels was pumped from a holding tank to the operation floor. Spray water was then diverted to two booster pumps to obtain the nozzle pressure requirements.

The water droplet sizes produced by the direct pressure nozzles had a mean diameter of 550 micron with a maximum size of over 2,000 micron. The corresponding evaporation time for these droplets is 4 and 50 seconds, respectively. With an average gas flow rate of 600,000 acfm the evaporation chamber represents a total gas residence time of 2 seconds. Figure 2 shows the relationship between droplet diameter and evaporation time for the given gas conditions. This shows that even the average droplets were not being completely evaporated inside the chamber thus causing water carryover into the gas main duct. The resulting wet, sticky gas caused severe dust buildup in the main duct as well as contributing to premature failure of the precipitator internals and platework. More importantly, the moisture content of the off-gas was inconsistent and generally lower than that required for maximum precipitator efficiency.

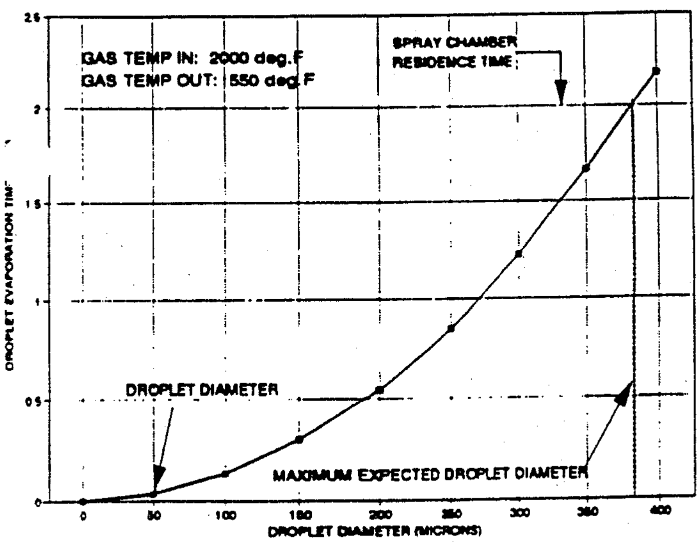

Figure 2. Droplet Evaporation Time

The main objectives of the new spray system was to:

- improve the off-gas moisture content thereby improving the ESP cleaning efficiency,
- minimize dust accumulation in the duct, evaporation chamber and ESP, and;
- eliminate the high pressure booster pumps and reduce the water spray rate.

Evaporation sprays are most effective when they provide uniform and full coverage across the gas stream. Figure 3 depicts the spray chamber configuration and new spray pattern. The water cooled wall panels were modified with cut-outs and by-pass lines in order to accommodate the nozzle installation. The nozzles were installed on BOF #2 during a turn-around outage with no increase in down time. After commissioning and proof of the system, an identical spray system was installed on BOF #1.

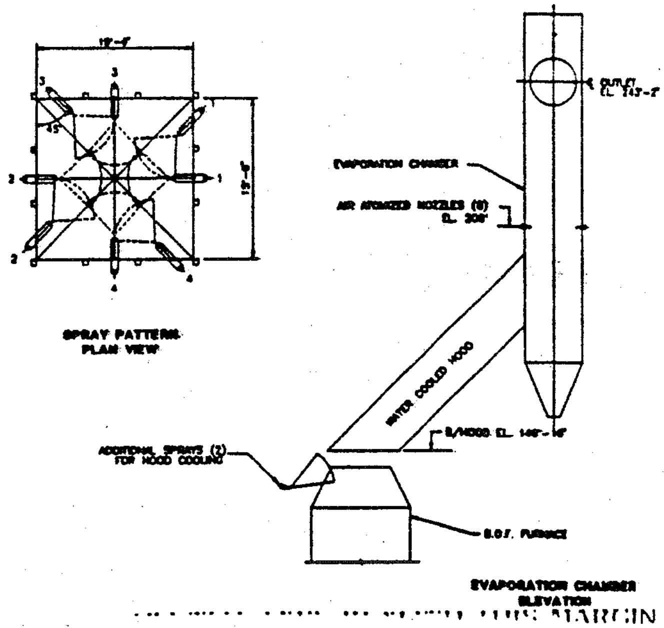

Figure 3. Spray Chamber Configuration

With a total residence time of 2 seconds available, Figure 1 shows that the maximum droplet size could be 380 micron for complete evaporation. Nozzles were thus selected to ensure that even the maximum droplet size would be completely evaporated inside the chamber. Figure 4 shows the effect on droplet size as a function of the water and air supply conditions for the selected air atomized nozzles[1]. With a mean diameter of 50 micron the maximum expected droplet diameter is 325 micron which satisfies the available 2 seconds for complete evaporation.

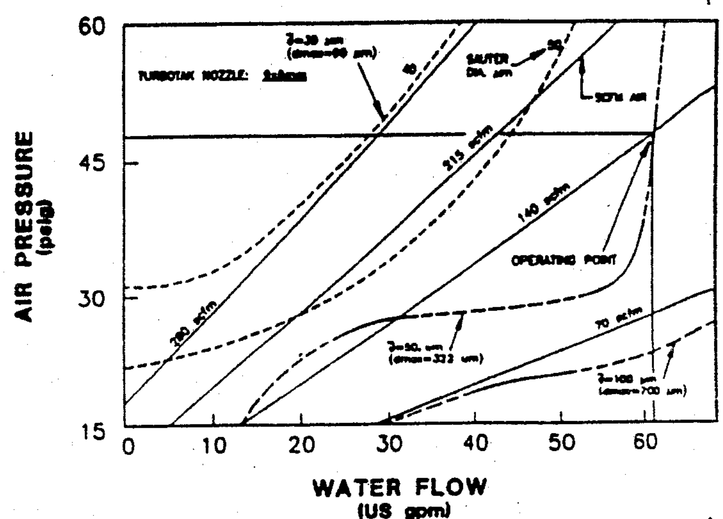

Figure 4. Air Atomized Nozzle Operating Characteristics

Nozzles of two different materials were purchased for evaluation purposes. Six nozzles were fabricated using 316L stainless steel and the other two were made from Inconel 310 alloy. The nozzles are cluster type each containing nine, 8mm orifice nozzles. The design operating conditions for each nozzle was 60 gpm with an air pressure of 50 psig in order to meet the droplet size and total flow requirements.

Off-gas heat content varies during the BOF oxygen blowing cycle, thus so does the amount of water required for gas conditioning. A programmable logic controlled was used to turn on/off each nozzle bank as required to utilize the available heat and maintain complete evaporation. The design settings are shown in Table I:

Table I. Initial Spray Control Settings

Off-Gas Temp [°F]	No. SPRAY BANKS ON	VOLUME [gpm]
200	1	120
225	2	240
250	3	360
275	4	480

Each spray bank was fitted with a water flow indicator in order to verify the flow conditions through each bank during commissioning. Each valve controlling atomized air was by-passed with a normally open line in order to allow secondary air flow through the nozzles to provide cooling and prevent plugging when turned off or not in use. A pressure reducing valve in the main air line was included in order to ensure that with any decrease in water flow to the nozzles, the airflow will increase resulting in a smaller droplet. The main air line was also fitted with a flow transmitter for commissioning purposes and troubleshooting. Atomization of water in the spray nozzle is critical for proper evaporation, thus an air low pressure switch was provided to alarm this condition.

AIR ATOMIZED SPRAY SYSTEMS PERFORMANCE

The new spray system has been in operation since 1991, and did experience some start-up problems as summarized below:

- build-ups were experienced in the ductwork and ESP material handling system, due to:
  - low set point temperatures for the spray system,
  - one of the nozzle tips detached from lance, which created an undesirable air and water flow distribution, and;
  - the pressure reducing valve in the compressed air line malfunctioned.

In order to remediate the problems above, water flow recorders were installed in the operator pulpit to closely monitor the operating conditions of the system. An interlock was added to activate the first spray bank with the oxygen blow and the remaining three banks were temperature controlled at 250°F, 350°F and 450°F. It was found that these operating points created consistent moisture levels reporting to the precipitator, as well as eliminating build-ups in the duct due to unevaporated droplets.

The original direct pressure nozzle booster pumps were de-commissioned after it was evident that the new spray system was capable of maintaining the off-gas temperature and moisture requirements.

The new nozzles were installed at the lowest elevation in the evaporation chamber as possible but the nozzles do not protect the inclined water cooled hood. It was realized that the original direct pressure nozzles not only conditioned the gas but also provided some cooling to protect the hood panels. It is intended to install one more pair of air atomized nozzles below the hood face in order to protect the hood panels, spray water at the location with the most available heat and also increase the allowable evaporation time.

The stainless steel nozzles have proven to be adequate for the described conditions, thus the more expensive Inconel nozzles are not required for this service.

BASIC CONCEPTS OF PRECIPITATION

Probably the best way to gain an insight into the process of precipitation is to study a relationship generally known as the Deutsch-Anderson equation[2]. It describes the factors involved in the collection efficiency of the precipitator as shown in its simplest form.

Collection Efficiency = $1 - \exp(-A{*}u/Q)$

Where:
- A = collection area (ft^2)
- Q = volumetric flowrate (acf/sec)
- u = migration velocity (ft/sec)

The exponent term u, known as the migration velocity represents the speed of movement of the particle toward the collector surface under the influence of an electrical field.

The equation demonstrates that the three key parameters which affect precipitator performance efficiency are effective collecting electrode surface area, volumetric gas flow rate through the precipitator and the particle migration velocity. Another parameter, which implicitly affects the performance of a precipitator is the dust resistivity. The term resistivity is a measurement of the ability to pass the flow of electric current through the layer of collected material.

As shown in Figure 5, dust resistivity is a sensitive function of the gas temperature and the moisture content[3]. As the dust resistivity increases it has an adverse affect on the precipitator collection efficiency as shown in Figure 6[3].

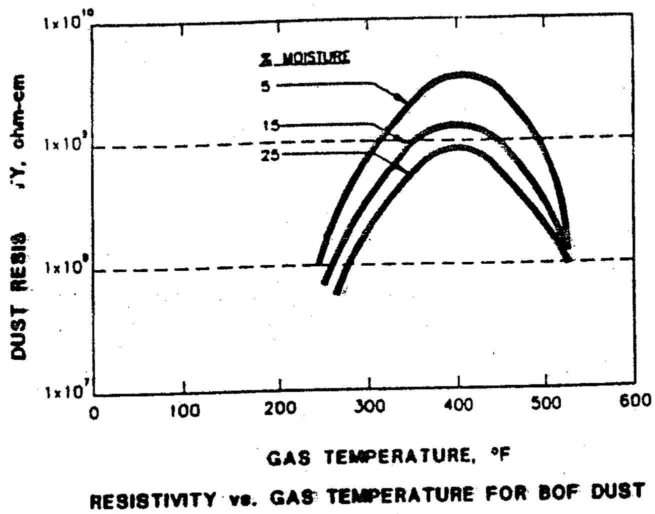

Figure 5. Resistivity vs. Gas Temperature for BOF Dust

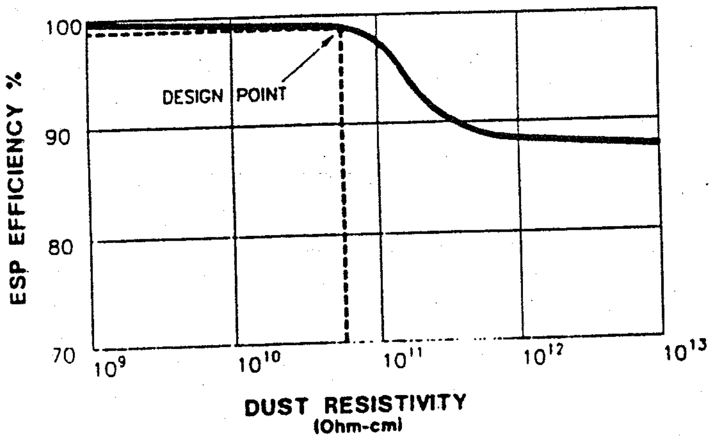

Figure 6. Collection Efficiency vs. Dust Resistivity

All precipitators operate better at a high temperature because of increased ion mobility in the corona, a region in which gaseous ions flow.

Typically, electrostatic precipitators on BOF's contain six to eight chambers with three to five fields per chamber. Collection area requirements, as shown in Figure 7, range from 200 to 600 ft^2/1000 acfm^3. The newer systems are at the high end of this range, and requirements on some are even higher.

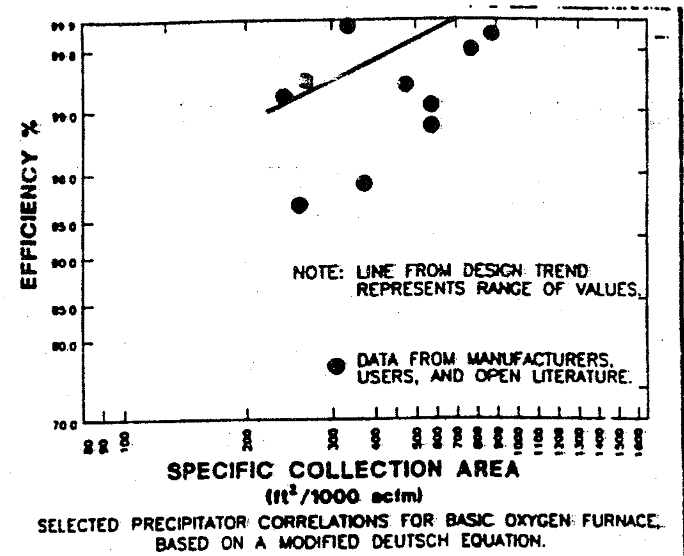

Figure 7. Collection Efficiency vs. Specific Collection Area

PRECIPITATOR MODIFICATIONS

While the performance of the precipitator system had improved with the addition of air atomized nozzles the desired cleaning efficiency was not met during low temperature periods of the blowing cycle. Therefore, it was decided to proceed with the engineering to install a new precipitator system in parallel with the existing double chamber units. The new precipitator will increase the collection area by 100%. The clean off-gas leaving the precipitator is ducted through the existing exhaust fans (three) to the discharge stack. A process flowsheet for the BOF off-gas system including the new precipitators is shown in Figure 8.

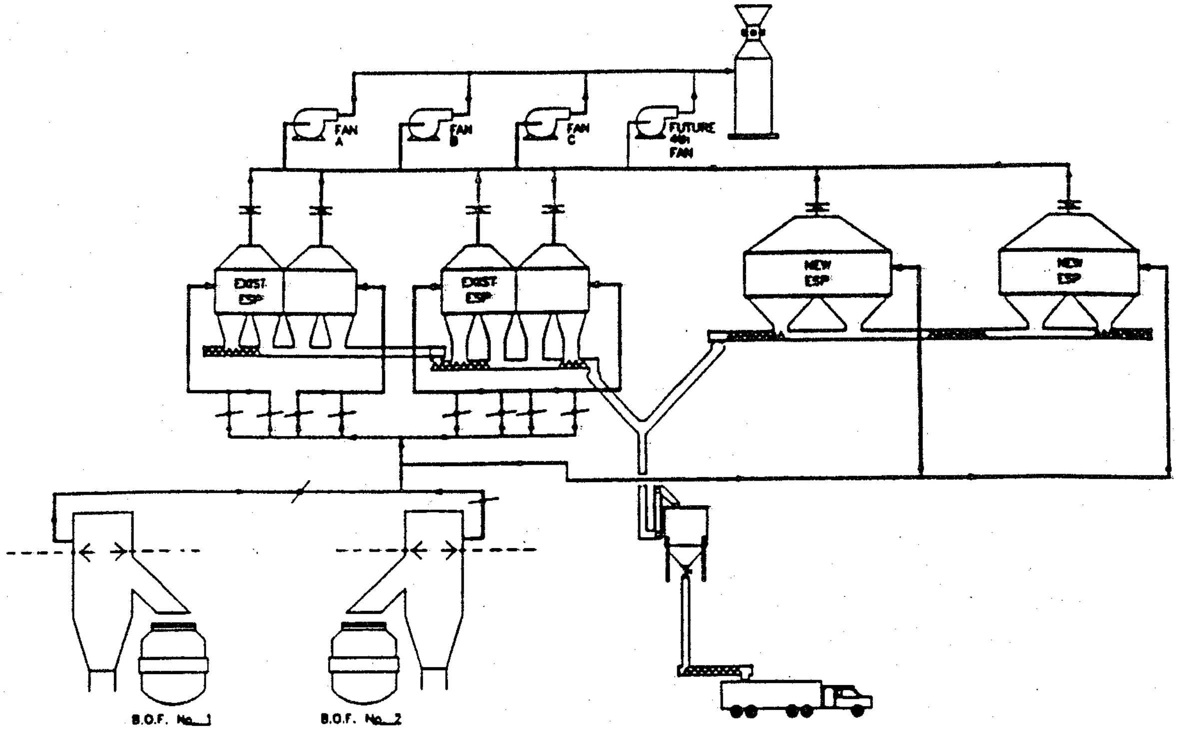

Figure 8. BOF Primary Fume System Flowsheet

The precipitator operating parameters for the existing system (i.e., 0% increase), 50% and 100% increase are presented below in Table II. The table shows that the ESP performance is acceptable for 50% and 100% expansion alternatives at the peak of the blowing cycle.

... projected surface collection area SCA and retention time for the future systems are well within the acceptable industrial practice range. The efficiency and outlet dust loadings presented are based on dust resistivity less than 10.5 x 10' [ohm-cm] and a favorable migration velocity.

The off-gas moisture contents and dust resistivity vary throughout the blowing cycle which have significant impact on the precipitator performance. The following migration velocities that represent the off-gas moisture contents at various stages of the blow have been used.

0.15 ft./sec.	0 - 4 min. into blow, and 18 - 22 min.
0.2 ft./sec.	4 - 6 min. into blow, and 17 - 18 min.
0.27 ft./sec.	7 - 16 min. into blow

The precipitator performance has been predicted during the entire blowing cycle for the existing system, 50% and 100% expansion. The results are demonstrated in terms of opacity in Figure 9. This figure presents the stack opacity in six minute averages which have been calculated by using the instantaneous opacity levels in one minute intervals. It is clear that 50% expansion is not acceptable and a 100% expansion was required to provide acceptable stack opacity levels throughout the oxygen blowing cycle.

Table II
EXISTING AND FUTURE OPERATING PARAMETERS
(ESP Performance at the Peak of the Blow)

Expansion / Parameters	0% Increase Existing System Two Double Chamber	50% Increase Existing Plus One Double Chamber		100% Increase Existing Plus Two Double Chambers	
	Existing	Existing	New	Existing	New
Gas Flow (acfm)	550,000	420,000	180,000	240,000	360,000
Gas Temperature (°F)	500	550	550	550	550
Collection Area (ft^2)	156,700	156,700	75,600	156,700	151,200
SCA (ft^2/1000 acfm)	285	373	420	653	420
Gas Velocity (ft/sec)	3.7	2.8	2.45	1.7	2.45
Ret. Time (sec)	6.4	8.4	10.7	14.1	10.7
Efficiency (%)	99.0	99.76	99.89	99.999	99.89
Outlet Dust (gr/ACF)	0.059	0.014	0.007	0.00	0.007
Overall Efficiency (%)	99.0	99.8		99.93	
Outlet Dust Loading (gr ACF)	0.059	0.012		0.0041	
Calculated Opacity (%)	25	4		2	

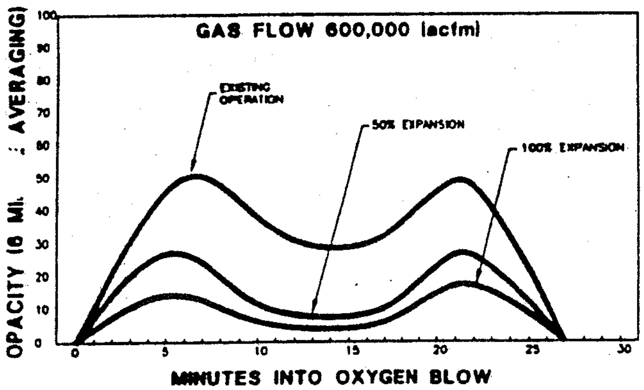

Figure 9. Predicted Opacity Levels

PHYSICAL MODELLING

The new precipitator that will be installed in parallel with the existing double chamber units share the existing precipitator outlet ductwork and I.D. fans including fan inlet ductwork. The system specifications are as follows:

- existing precipitator gas flow 60,000 acfm/chamber (4 chambers)
- new precipitator gas flow 180,000 acfm/chamber (2 single chambers)
- Total gas flow
  600,000 acfm @ 500°F; -15 in. w.g. static pressure

It was decided to conduct a physical air-flow model study of both the existing and new gas cleaning systems. A 1/16 - scale plexiglas model of the system including the ductwork, precipitator nozzles and chambers, less precipitator internals, was constructed and tested to verify flow distribution and pressure losses in the system.

The objectives of the study were as follows:

- to measure the off-gas velocity distributions and pressure losses in the model and from these measurements predict prototype values at the design flow condition.
- to determine the location and configuration of gas-flow distribution devices, to satisfy the specified flow proportion criteria
- to determine the location and configuration of gas-flow distribution devices to minimize the pressure loss in the system.

CONCLUSIONS

The air atomized spray nozzles, which replaced the original direct pressure nozzles has reduced moisture and dust buildup in the off-gas ducting, as well as the ESP and dust handling system. These nozzles improved the moisture content of the off-gas, thus improving collection efficiency. A 100% expansion of the existing ESP was required to meet the gas cleaning objectives. A scale model of the future system was a valuable tool in designing ductwork and flow distribution devices used to meet flow distributions and minimize pressure drop.

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