Better testing

Richard F. Storm, Stephen K. Storm and Sammy Tuzenew, Storm Technologies, Inc., US, ***consider how to conduct a comprehensive diagnostic test on a pulverised coal-fuelled boiler.***

Tuning of a large pulverised coal (PC) fired boiler must often be more precise with some coals than others. For example, four coal quality variations can make a drastic difference in overall boiler performance. Coal quality factors that can have a significant impact on boiler capacity, slagging, NOx, and steam temperatures include:

- Ash fusion temperature.
- Hardgrove Grindability Index (HGI).
- Fuel fixed carbon/volatile matter ratio.
- Mineral ash constituents that influence slagging.

The concept of the diagnostic test is to find the root causes, and quantify opportunities for improvements to boiler combustion performance.

Ash fusion temperature

If the ash fusion temperature is too low, it can contribute to slagging at the superheater inlet as shown on Figure 1. Ideally, the softening temperature will be 100 - 150 ˚F (38 - 66 ˚C) above the actual flue gas peak temperatures at the furnace exit.

When the ash fusion temperature is very high, at approximately 2800 ˚F (1535 ˚C), greater heat is absorbed in the lower furnace, and lower than design steam temperatures may be experienced, which reduces the overall unit efficiency.

Pulveriser capacity

Pulveriser capacity should be thought of as the combination of three factors: coal throughput, coal HGI and coal fineness. Explicitly, pulveriser capacity is not simply coal throughput; it is coal throughput at a certain fuel HGI, raw coal size and fuel fineness. In addition, acceptable coal rejects and available drive motor power are important factors.

Coal pulverisers are at the heart of a modern pulverised coal-fired boiler. Pulveriser performance means either 'good' or 'poor' boiler performance. Good boiler performance includes such factors as NOx, fly ash unburned carbon content, bottom ash carbon content, boiler slagging and metals temperature limits.

HGI

HGI has a large effect on pulverised fuel fineness and distribution. Typical boiler/pulverisers from the 1960s and 1970s were designed for 50 HGI and 70% passing 200 mesh. To optimise performance of these older pulverisers for fuels with an HGI of 40 and for fineness of 75% passing 200 mesh (for optimum low-NOx burner performance) requires greater grinding pressures, more frequent mill overhauls, or replacement of the pulverisers with larger mills.

NOx-friendly fuels

Fuel volatile matter content, FC/VM ratio, and elemental nitrogen have a great impact on NOx emissions. Higher volatile matter fuels are more NOx-friendly. Therefore, when tuning a pulverised coal-fired boiler for the best NOx, some fuels require more precise attention than others. For example, if a fuel has low volatile matter, and higher fuel nitrogen, it will inherently create higher NOx. When this fuel is combined with high primary airflows and imbalanced secondary airflows, the NOx levels are higher

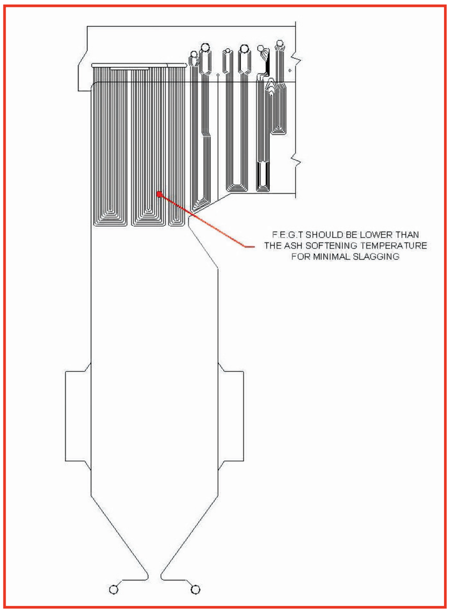

Figure 1. Slagging at the superheater inlet.

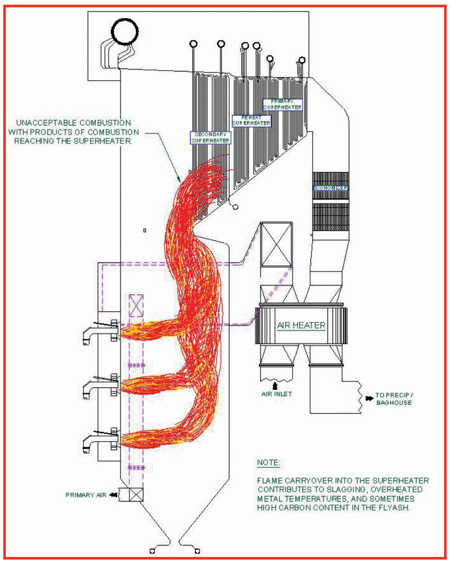

Figure 2. Active combustion continuing up into the superheater.

Table 1. Proximate analysis	
As received	**Typical**
Moisture (wt%)	6.3
Volatile matter (wt%)	34.77
Fixed carbon (wt%)	51.85
Ash (wt%)	7.07
Sulphur (wt%)	1.88
Heating value (Btu/lb)	13,049

Table 2. Proximate analysis	
Volatile matter (wt% dry)	37.11
Fixed carbon (wt% dry)	55.34
Ash (wt% dry)	7.55
Sulphur (wt% dry)	2.01
Heating value (Btu/lb)	13,926
MAF (Btu/lb)	15,036

Table 3. Ultimate analysis		
	Dry	**As received**
Carbon	76.81	71.97
Hydrogen	5.07	4.75
Nitrogen	1.6	1.5
Chlorine	0.11	0.1
Sulphur	2.01	1.88
Ash	7.55	7.07
Moisture	-	6.3
Oxygen)	6.85	6.42

Table 4. Ash fusion temperatures			
	Reducing	**˚F**	**˚C**
IT		2145	1174
ST	H = W	2274	1246
HT	H = 1/2W	2416	1324
FT		2448	1342
	Oxidising	**˚F**	**˚C**
IT		2515	1379
ST	H = W	2274	1246
HT	H = 1/2W	2601	1427
FT		2615	1435

Table 5. Heating value as received		
	Gross	**Net ISO**
Btu/lb	13,049	12,565
kcal/kg	7253	6985
GJ/Mt	30.33	29.21
HGI	53	

than if the airflows were optimum. The normal operators' reaction to a higher NOx level is to reduce the boiler excess air. When this is done, if the air/fuel mixtures are non-optimised, then active combustion continues all the way up into the superheater, as shown in Figure 2.

Mineral ash constituents

Certain ash constituents can influence furnace exit slagging. For bituminous fuels, the most repeatable troublesome element is iron. Additionally, the acid/base ratio of other constituents can be problematic. Some lignitic fuels also have specific elements that change the characteristics of slagging and fouling.

Suffice to say, some fuels have greater tendencies to slag at the upper and lower furnace and/or foul the convection pass than others. Typical bituminous coal ash fusion and mineral ash analyses are shown in Tables 1 - 5.

The reducing atmosphere ash softening and fluid temperatures should be noted. When a particular coal is fired that has a substantially lower fusion temperature in a reducing environment, it can create significant challenges in furnace exit slagging. Note that the ash fluid temperature is 167 ˚F (70 ˚C) lower in a reducing environment than in an oxidising environment.

Referring back to Figure 1, it is ideal if the furnace exit gas temperature (FEGT) is below the ash softening temperature. Often, when tuning boilers for today's NOx requirements, the furnace exits of many boilers have almost zero oxygen at specific locations. When fuel and air are highly stratified in the furnace, as with many low NOx burner systems, and a fuel or blend of fuels with a high slagging index is utilised, excessive slagging can occur. Importantly, when some areas of the upper furnace are at 'zero' excess oxygen, or a reducing environment, not only does the coal ash melt or become sticky, but the active combustion also creates much higher gas temperature lanes. This can sometimes result in the temperature rising by 300 - 500 ˚F (149 - 200 ˚C).

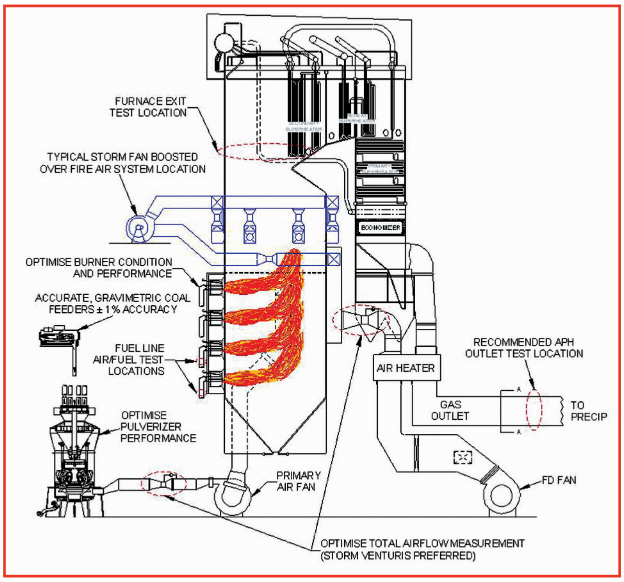

Figure 3. Testing boiler furnace inlets.

The four factors of coal quality can be addressed by applying the 13 essentials of optimum combustion (Table 6). This is a methodical approach to optimising the furnace performance.

Comprehensive diagnostic test

Using the 13 essentials as a checklist, testing of the boiler furnace inputs is accomplished using test equipment as shown in Figure 3.

The following outline is a description of a full comprehensive diagnostic test for a pulverised coal-fuelled boiler. The testing to be completed during a comprehensive diagnostic testing is as follows:

- Force draft fan flow measurements (using an F/R probe).
- Furnace exit O_2 traverses (using a water-cooled HVT probe).

Table 6. The 13 essentials for optimum combustion	
1.	Furnace exit must be oxidising, preferably 3%
2.	Fuel lines balanced to each burner by 'clean air' test ±2% or better
3.	Fuel lines balanced by 'dirty air' test, using a dirty air velocity probe, to ±5% or better
4.	Fuel lines balanced in fuel flow to ±10% or better
5.	Fuel line fineness shall be 75% or more passing a 200 mesh screen. 50 mesh particles shall be less than 0.1%
6.	Primary airflow shall be accurately measured and controlled to ±3% accuracy
7.	Overfire air shall be accurately measured and controlled to ±3% accuracy
8.	Primary air/fuel ratio shall be accurately controlled when above minimum
9.	Fuel line minimum velocities shall be 3300 fpm
10.	Mechanical tolerances of burners and dampers shall be ±0.25 in. or better
11.	Secondary air distribution to burners should be within ±5 - ±10%
12.	Fuel feed to the pulverisers should be smooth during load changes and measured and controlled as accurately as possible. Load cell equipped gravimetric feeders are preferred
13.	Fuel feed quality and size should be consistent. Consistent raw coal sizing of feed to pulverisers is a good start

- Boiler exit/air heater inlet O_2, CO, NOx and temperature traverses (multi-point bubbler system and temperature data acquisition system).
- Air heater outlet O_2, CO, NOx and temperature traverses (multi-point bubbler system and temperature data acquisition system).
- Induced draft fan flow measurements (using a F/R probe).
- High volume fly ash sampling.
- Fuel line clean air balancing via two team traverses and orifice plates.
- Fuel line dirty air balancing via storm dirty air and coal sampling method.
- Primary air flow hot 'K' factor traverses.
- Fineness testing (fuel samples to be sieved through 50, 100 and 200 mesh sieves at a minimum and 140 mesh sieve if available).
- Static pressure from the F.D. fan to stack.
- ID fan discharge flue gas analyses.

Comprehensive diagnostic testing provides the means to identify root causes of problems such as capacity, reliability, or efficiency affecting factors. Opportunities for potential improvements for coal-fired boilers are shown in Figure 4.

Optimum combustion in coal-fired boilers relies upon complete combustion in the burner belt zone and NOx emissions being below the established limit. There should be minimal fly ash carbon content (minimal fly ash LOI, approximately 3 - 5% for eastern coals) and maximum heat absorption of the furnace with minimal slagging. Design steam temperatures should be achieved with minimal de-superheating spray water flow. Additionally, there should be minimal fouling of the convection pass for optimum boiler exit gas temperatures.

Experience has shown that many opportunities to improve large pulverised coal-fired boilers can be addressed by implementing a combustion improvement programme. This begins by achieving the prerequisites for optimum combustion. Achievement of the requisite combustion parameters can be worked towards once the non-optimised parameters are identified.

Prerequisites

The prerequisites for optimum pulverised coal firing combustions are as follows:

- Duct and boiler air in-leakage not exceeding 5% from the furnace to the air preheater.

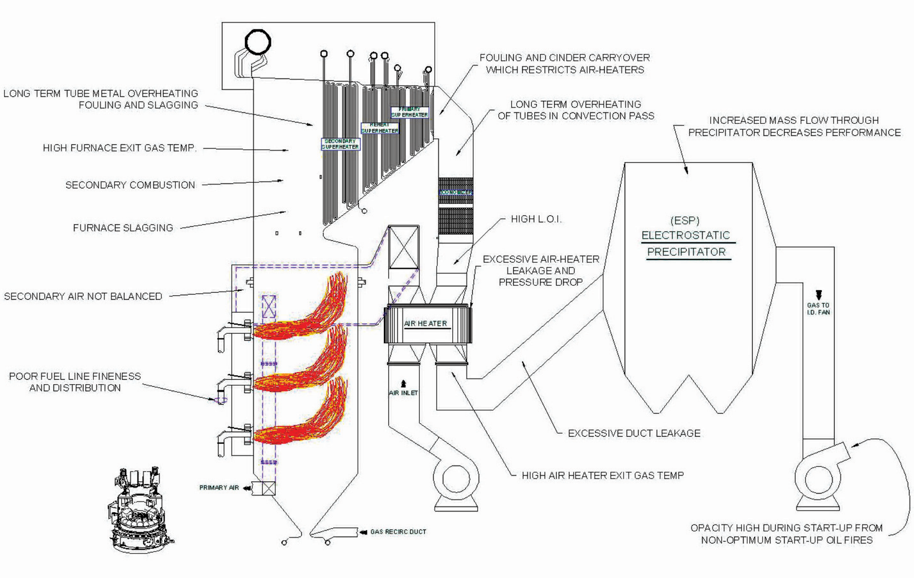

Figure 4. Potential improvements for coal-fired boilers.

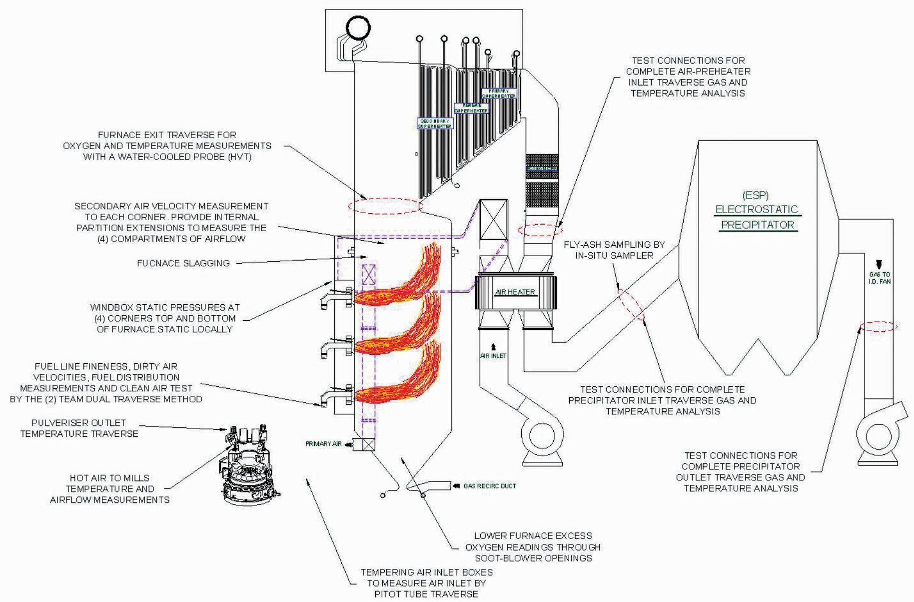

Figure 5. Locations for diagnostic testing.

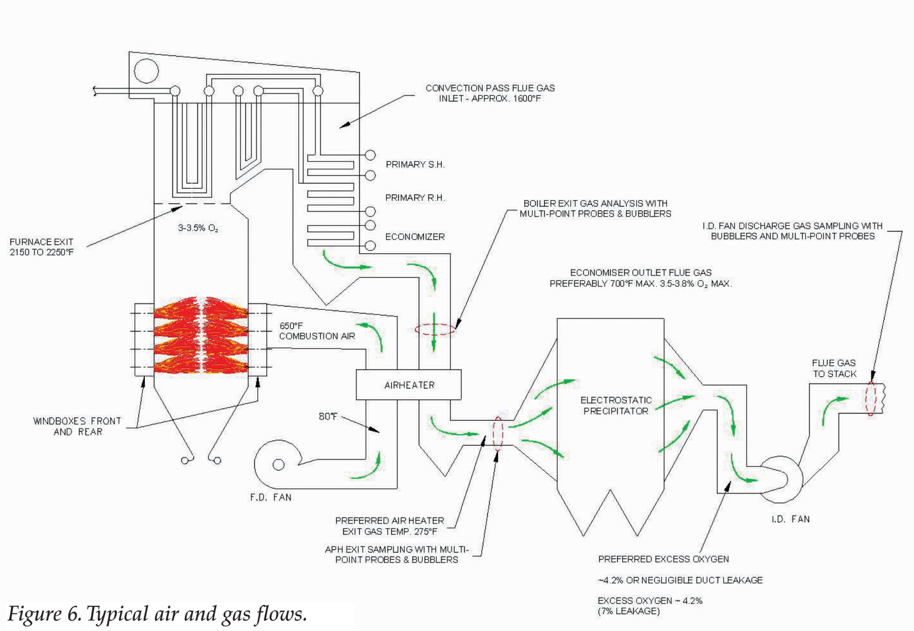

Figure 6. Typical air and gas flows.

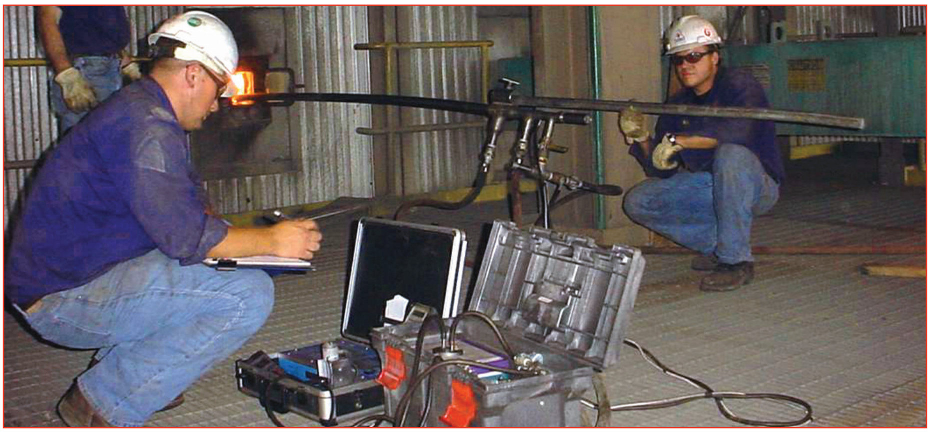

Figure 7. Using a water-cooled high-velocity thermocouple.

Figure 8. A typical multi-point probe and bubbler grid.

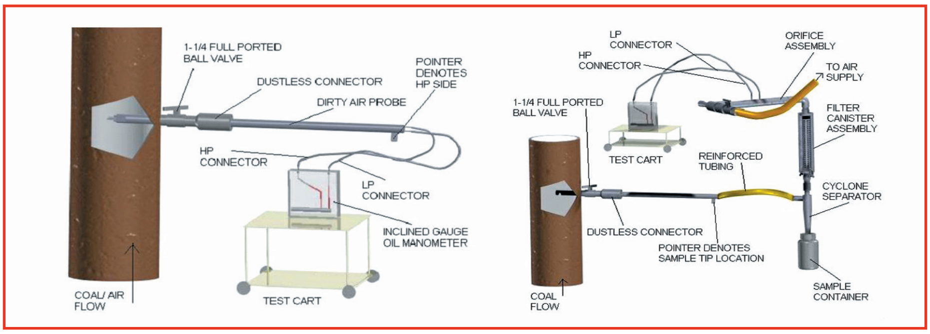

Figure 9. The Storm dirty air probe and isokinetic coal sampler.

- Air Heater Leakage of less than 10% leakage.
- Duct leakage from the air preheater to the ID fans shall not exceeding 5% (e.g. 1% oxygen rise).
- The 13 essentials of optimum combustion should be observed.

Diagnostic testing is carried out to identify opportunities for combustion improvements for coal-fired boilers. The test locations are shown in Figure 5. Typical boiler air and gas flows, preferred temperatures and excess oxygen values for optimum efficiency are shown in Figure 6.

Fan flow measurement traverses

Force draft and induced draft fan flow traverses should be performed to determine flow rates. A forward/reverse probe can measure the velocity heads, temperature, and static pressures. Flow rates will be measured and calculated in ACFM and lb/hr.

Furnace HVT traverses

Determing the average oxygen levels at the furnace exit and boiler exit planes can be obtained using a high-velocity thermocouple (HVT) water-cooled probe. The HVT traverses is a very important test in diagnosing combustion-related problems. The test location or traverse plain is above or near the nose arch of a boiler. The HVT probe is marked at 2 ft intervals and O_2 and temperature readings are obtained at each 2 ft increment. The HVT probe is typically exposed to temperatures ranging from 1500 to 2500 ˚F (816 - 1371 ˚C), requiring the probe to be water-cooled. HVT performs the following functions:

- Quantifies FEGT.
- Ascertains furnace temperature profile.
- Quantifies furnace oxygen level.
- Ascertains furnace oxygen profile.

The furnace exit gas conditions of temperatures, carbon monoxide and excess oxygen levels are areas with opportunities for improvement in the burner belt zone.

The key to optimising furnace combustion is the use of a water-cooled high-velocity thermocouple (HVT) probe, which is shown in Figure 7.

Multi-point probes and bubbler(s)

Boiler exit, air heater inlet and air heater outlet locations are traversed using multi-point probes and bubbler(s) configuration. Multi-point bubblers are placed on the closest elevation to the test location in order to obtain a composite gas sample from the APH inlet duct. In addition, the bubblers are placed near the APH outlet duct test location level so that a composite sample can be drawn. Each of the multi-point bubblers utilises aspirating air to draw the gas samples from the multi-point probes into and out of the bubbler. The gas constituents can be measured using a Storm gas conditioner kit and ECOM analyser capable of reading O_2, CO and NOx.

The gas side temperatures at the boiler exit/air heater inlet and air heater outlet locations are taken in a grid similar to the flue gas samples. A number of sampling points and test grids are based on ASME test code requirements for test tap layout for equal areas. The temperature measurements are obtained with Type K thermocouples, and a thermocouple data acquisition system records the temperatures every 5 - 10 mins. Figure 8 shows a typical multi-point probe and bubbler grid.

In-situ flue dust samplers

Fly ash sampling with a Storm in-situ/near isokinetic sampler collects flue dust/ash samples. The sample is then tested to measure coarse particle LOI, fine particle LOI, and overall LOI. The presence of excessive coarse particle LOI indicates poor fineness from the pulverisers.

Pulveriser performance testing

Pulveriser performance testing consists of clean airflow testing, dirty air and coal sampling, fineness sieving analysis and primary hot 'K' Factor traverses.

The baseline clean air testing should be completed to determine system resistance balance from pipe to pipe.

Balancing system resistance of fuel lines on clean air is the first phase of a comprehensive fuel and air balancing programme. It is important to remember that clean air balancing is an important factor in optimising pulveriser fuel and air balance. However, it is only one of many critical parameters that must be addressed. Optimum fuel balance is achieved through a combined effort aimed at improving pulveriser grinding efficiency, improved fineness and classifier timing and condition.

A four-person test crew is recommended to perform dirty air traverses and isokinetic coal sampling to obtain and accomplish the following results:

- Ascertain relative pipe-to-pipe fuel balance.
- Quantify individual fuel line air to fuel ratios.
- Quantify pulveriser air to fuel ratio.
- Quantify individual fuel line velocity and airflow.
- Ascertain pipe-to-pipe airflow balance.
- Quantify fuel line temperature and static pressure.
- Obtain representative fuel samples for coal fineness analysis.


Figure 10. Flow nozzles.

Also to be determined during the tests are all of the available control indications, mill hp/t and mill settings. In Figure 9, a Storm dirty air probe and isokinetic coal sampler are shown for reference.

Primary air traverses are performed in conjunction with, or immediately before or after a mill test. Primary flow traverses are performed at a minimum of two tests, at different load points. If possible, it is recommended to perform the Storm hot 'K' factor test at three different load points. By doing so, an averaging 'K' factor across the three load points can be determined and applied to the controls if necessary.

Improved primary airflow measurement and control is one of the most frequent opportunities for improvement, for example by utilising venturis or flow nozzles (Figure 10).

Comprehensive diagnostic testing helps to identify problems with capacity, reliability, or efficiency affecting factors._■