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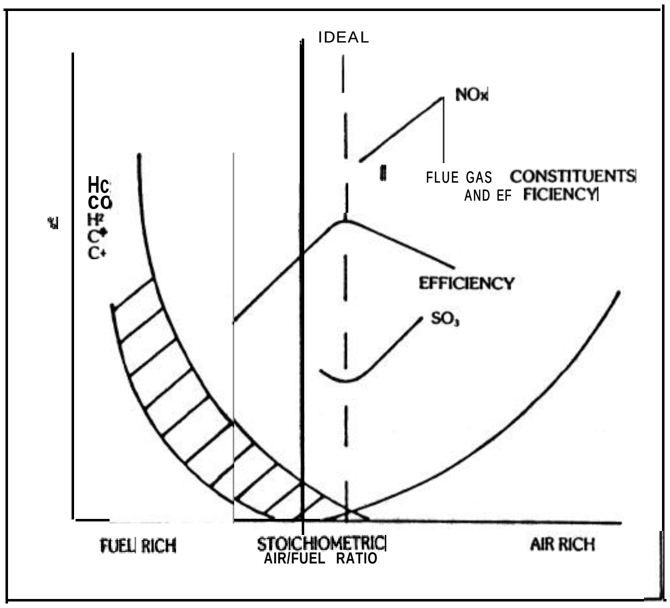
Servomex

Current trends in fine control of the combustion process by use of flue gas analysis

Accurate measurement of flue gas components allows optimisation of the combustion process essentially by enabling comparison of the actual concentration of a selected component with the ideal concentration and tuning the air/fuel ratio accordingly. Such 'Trim Control' is, then, a feedback technique which has been used for a number of years in one form or another, from manual adjustment derioed from a spot-check measurement using a portable instrument to automatic control based on continuous measurement of a number of components. In this article, Dr Sam Langridge *of Seruomex Ltd, indicates some of the latest developments in combustion control techniques*

from Works 1985

Combustion Control



From the point of view of manufacturers of such equipment the small medium industrial and commercial boiler market has been recognised since the middle seventies as potentially the most attractive prospect for sales. In the U.K. alone there are about 50,000 boilers in the range 2 to 20 MW thermal input which are generally package shell boilers, fully modulating but relying on parallel mechanical control of air and fuel valves. The main advantage of the application of an automatic trim system on such boilers is to elimnate the control system hysteresis notoriously inherent in many burner systems, although there are other benefits such as compensation for changes in atmospheric pressure, humidity and calorific value of the fuel and for deterioration in burner performance.

The improvement in efficiency available varies greatly and can be as good as 6 to 7% on poorly maintained plant, but is more likely to be between 1 and 3% on the average gas or oil fired boiler. It must be said that it is usually (especially on smaller plant) not easy to *proue (or disproue) changes of this order.* Very accurate monitoring of fuel and steam flow, correlated with the pattern of firing rate over a reasonable period is required.

That does not mean, however that appreciable genuine savings cannot be made. They can and are, especially as both the sophistication and the reliability of trim equipment available has increased markedly in the past two to three years, **but a salesman who guarantees a 4% saving without a thorough understanding of both the combustion process in general and the particular characteristics of the boiler in question is being less than honest.**

A successful trim system needs to be good in four areas: –

- The application must be correct. Boilers with a history of back end problems and travelling chain grate stokers for example, need particular care.

- The mechanical integration of the trim with the existing control system needs to be reliable. One of the difficulties of trimming direct positioning type burners is the need to replace or modify an existing linkage to an air damper with a mechanical method of altering the length of the linkage (and thus damper position) without in any way affecting the freedom of the linkage to move during normal modulation.

- The control philosophy needs to be sound and flexible enough to deal with a variety of burner/boiler systems. It should be noted here that the great majority of trim systems are retrofitted to existing burners.

- The accuracy, reliability and speed of the analysis are of great importance. This area represents a prevalent yet little realised weakness of many systems. The most sophisticated electronics Is no substitute for good feedback. A related problem is the choice of flue gas component(s) on which the trim is to be based. A control system based on the breakthrough of carbon monoxide is of no use if the precursor of incomplete combustion is smoke, as it often is on heavy fuel oil fired plant.

Analysis of the combustion process

The relationship between flue gas components, combustion efficiency and fuel/air ratio are summarised in figure 1. The key requirement is to establish the point at which the volume of hot escaping flue gas is minimal (i.e. the excess air or oxygen is minimal) consistent with complete combustion of the fuel. This point will correspond to an oxygen concentration; and indeed oxygen is by far the most commonly measured flue gas component. It is a relatively inexpensive and (with some reservations) reliable measurement which gives a direct measure of combustion efficiency. On the other hand, the ideal oxygen level varies with boiler load, fuel and individual burner. Also any air leaks into the boiler system will lead to an erronious reading, but, although often quoted as a disadvantage, this is in practice very rarely a problem on industrial shell boilers.

The use of carbon monoxide as control parameter is increasingly popular, particularly with the introduction of non-sampling (or x-stack) infra red measurement. Such analysers are up to five times as expensive as O_2 instruments, however, and have greater maintenance and reliability problems. Their main drawback is that CO is simply not a good control parameter. It cannot be relied upon to be the first indicator of incomplete combustion for fuel oil fired plant and, where it is useable in that sense, the control system needs to approach a breakthrough of CO from a (safe, clean) air rich position which means that it is continually “bouncing off” a CO rich situation – an inherently unstable control philosophy.

This measurement also lacks the flexibility of oxygen as a sole control component in the sense that (all other things being equal) it forces the running of the boiler at maximum combustion efficiency which (if there are back end temperature problems, for example) may well not be desirable.

From a theoretical point of view there is no question that the most satisfactory control philosophy is to measure oxygen, carbon monoxide, hydrocarbons, smoke (essentially small carbon particles), flue or back end temperature and emissions of larger carbon particles. Flue gas monitoring and control systems incorporating all but the last of these measurements are available but are expensive and have a significant requirement for maintenance and therefore customer expertise.

It should be appreciated that a good oxygen based system should be able to get within 0.2% of maximum burning efficiency and that the additional cost of multi-component measurement must be balanced against this relatively small extra saving.

Control philosophy based on O_2 feedback only

Early oxygen trim systems, at least as applied to medium sized industrial boilers, simply compared the measured oxygen to a value pre-programmed in the controller (the set-point) and put out a correcting signal proportional to the error. in practice this may have been proportional/integral control *via* electrical pulses to an actuator which directly, or *oia* a linkage system, slightly altered the position of the air damper relative to the fuel valve. The O_2 set point, of course, varies with boiler load and this set point curve, or 'burner line' would be approximated often rather crudely in the controller.

Modern microprocessor based trim controllers have a more refined and flexible control routine. If the boiler changes load rapidly compared to the real analyser response time (as opposed to that claimed in the manufacturers specification sheet) then the earlier trim systems could, in terms of efficiency, do more harm than good. Current systems feature a variety of feed-forward control mechanisms in addition to the original O_2 feedback.

At its simplest the position of the trim actuator at all firing rates can be taught to the controller during initial set up. During rapid modulation, the controller will ignore the oxygen signal and position the trim actuator to the pre-programmed position. Ideally the controller would then wait for the boiler to settle before final correction based on the oxygen signal.

A better solution is a system which positions to the pre-programmed trim actuator position during rapid modulation and makes a fine correction based on the oxygen feedback when the load is relatively stable. When modulation is less rapid the actuator look-up table is modified as a result of the oxygen feedback and used in the control algorithm for rapid positioning. The modifications to the look-up table are, however, wiped out when the boiler reverts to rapid modulation (when the trim is in feed-forward or load control) – i.e. there is a gross change in conditions. This greatly reduces the possibility of changing the main control table on the basis of erroneous information.

In practice this method of control produces excellent results. The crucial parameter is the rate of load change at which the system changes from feed-forward control to adaptive feedback control.

Trim system features

A modern O_2 trim system will have a number of other settable features. The oxygen set point curve or burner line should be set up dynamically using appropriate combustibles measurement and the installed trim actuator to vary the air/fuel ratio. The controller must be capable of storing at least two fuel burner lines. A variety of alarm inputs (probe failure, actuator failure, large oxygen deviations etc.) will set the trim actuator to a neutral, air-rich position, permanent (i.e. manually resetable) or temporary (auto-resetable on alarm clearing) depending on the nature of the problem.

A useful feature is one that monitors the degree of actuator movement over a period of time and gives a visual indiction (without neutralising the trim) should there be a significant change in the pattern of required movement. This may indicate, for example, a need to service the burner.

Fine control at low firing rates can be difficult due to the non-linear characteristics of a damper in an air duct. The ability to vary the control system gain to ensure that there is no hunting about the O_2 control point is necessary. A useful possibility made available by the existance of an actuator look-up table is the opportunity, below a certain load, to back off the control to ensure that the control point is approached from an air rich rather than a fuel rich position.

Control based on multivariable trim

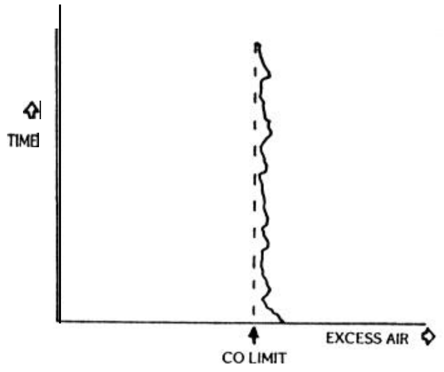
Some theoretically attractive control philosophies have been developed based on continuous measurement of a number of flue gas components. Using x-stack or insertion I.R. to measure CO, hydrocarbons and smoke and zirconia analyser for oxygen, a control algorithm which includes a target value for all of these components and continually chooses the best one to dptimise, can work well. In practice, this may work according to the table.

Measured parameter	Target value	Measured value	Required action	Action taken
CO	150 p.p.m.	90 p.p.m.	−0.1% O_2	←
HC	100 p.p.m.	20 p.p.m.	−0.3% O_2	x
Opacity	7.5%	4.5%	−0.2% O_2	x
O_2	1.0%	1.3%	−0.3% O_2	x

The measured value and, hence of course, the action taken will vary as the combustion conditions change.

In practice what may be more important is not the theory of

Continuous operation at a limit causes unstable air flow and thermal cycling of the boiler.

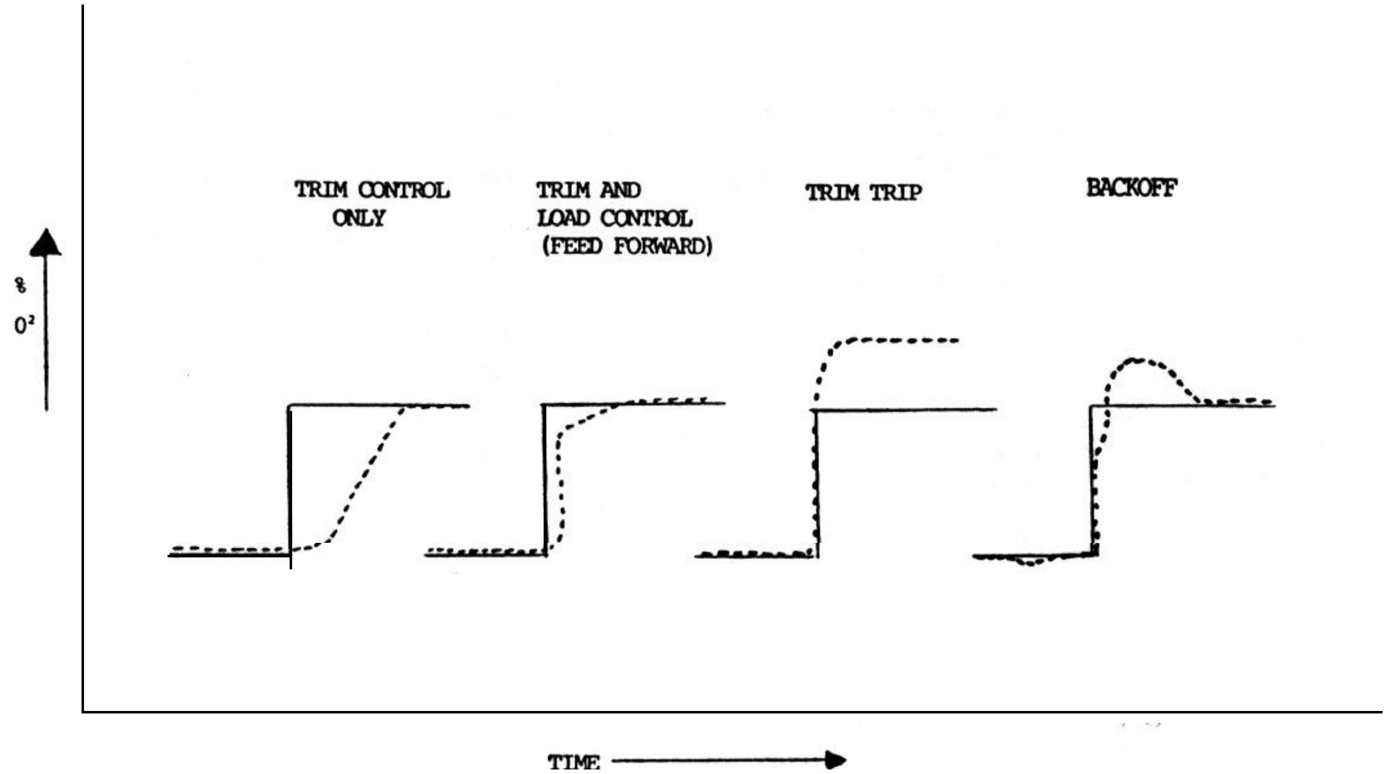


control but the practice of achieving reliable. maintenance free continuous multicomponent measurement at an acceptable price. Flue gases are in reality, hot dirty corrosive environments and even basic zirconia based oxygen analysis is not as reliable as some manufacturers would claim.

Assuming that X-stack or insertion I.R. becomes less expensive and more reliable, an alternative low cost combination of CO/O2 and opacity analysis linked to a trim control system could, in the near future, be a viable product for the medium size industrial boiler market. The CO and smoke measurements could be used to automatically establish an O_2 burner line at intervals and would otherwise comprise an alarm input to neutralise (air rich) the trim actuator.

Such a scheme would not demand the accuracy or reliability of CO/Opacity measurement required when these are used for primary control and could consequently enable the use of lower cost instruments.

Figure 3



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