Paper prepared for the 20th North American Waste-to-Energy Conference
NAWTEC20
April 23-25, 2012 Portland, Maine, USA

NAWTEC20-7030

PRACTICAL EXPERIENCE ON OPTIMIZATION OF COMBUSTION WITH EXPERT SYSTEMS FROM 12 WTE PLANTS IN EUROPE AND CHINA

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ABSTRACT

Process optimization of Waste to Energy plants (WtE plants) is of particular interest because control performance is crucial for the profitability of the overall operation of the plant.

WtE plants represent very large investments and an optimal efficiency in operation is crucial for the return of the investment. Process optimization including optimal control of the abnormal operating situations when the waste quality is out of the normal range is thus very attractive in order to increase the profitability and efficiency of the waste incineration operations.

This presentation will describe how high-level control based on expert system can be used in a practical and convenient way to provide a more efficient operation of a WtE plant and provide a capacity increase of 3-6% or more and thereby be a very attractive investment for an existing or new WtE plant operator.

NOMENCLATURE

A high-level control system shall be defined as a system that acts at the same level as the operators. The name high-level control, also defined or mentioned as an expert system in this paper, provides functions that are very difficult to efficiently handle by the normal, conventional control system. A high-level control system will react predicable and consistent in its control of the WtE plant like an experienced operator.

INTRODUCTION

Denmark is located in the northern part of Europe, and the use of district heating for heating of houses has been widespread all over the country for decades.

Political and public interests to provide efficient systems in order to handle the municipally-generated household waste have during many years resulted in extensive use of WtE plants. These systems are operating with very high efficiency due to the combined use of the energy produced for electricity and heating.

Denmark is known for being one of the leading countries in the world in this field.

A number of advanced technologies have been developed, establishing a very positive environment for creating new technology and expertise. Among these technologies are expert systems applied for high level control of the combustion process.

THE WTE CONTROL CHALLENGES

A WtE plant is divided in different critical functional areas, each heavily influencing the operation such as: waste feeding system, waste combustion, the energy transformation in the boiler and the flue gas cleaning system.

An efficient combustion control is crucial for the overall efficient operation of the WtE plant.

The main challenges when operating a WtE incineration plant are:

- To handle the fluctuations in the waste composition.
- To take care of long time delays in the process.
- To handle multiple inputs from the process, such as O_2, CO, steam flow, temperatures in combustion system and boiler, the pressure drop over the grate, combustion air flows etc.
- Efficiently use the operator observations about the waste category.

- Handle the process dynamics depending on the actual plant maintenance level including the contamination of the furnace and boiler.
- Secure the emission levels on the plant within the levels accepted by the authorities.

A typical loop control display from a plant with conventional control is shown in figure 1:

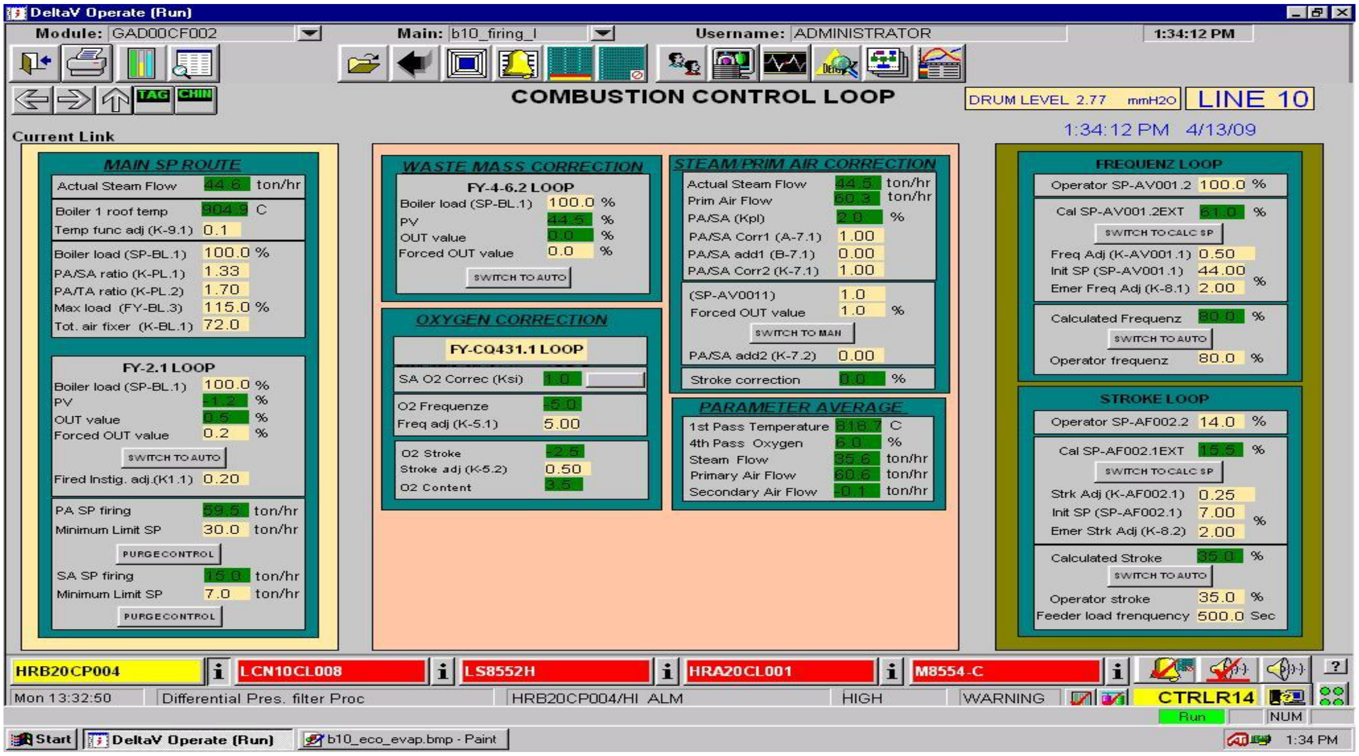

Figure 1, typical loop control display

A conventional PID based process control scheme has the purpose of handling the various process fluctuations. Some process dynamics has short time delays, others has long time delays. During the control system design the engineers have to define some limitations in response time in order to be able to handle the most important process fluctuations efficiently. Furthermore, the number of process signal inputs to the loop controllers as well as the number of outputs has to be limited in order to reduce the complexity of the design and to simplify the system's maintenance.

Due to narrowly defined operating ranges for PID based control, a conventional control scheme cannot always efficiently control a WtE plant when heavy fluctuations occur. The results are too slow or too fast reaction to some process fluctuations and the operators must often take over the control by putting the PID loop controllers into manual.

A conventional loop PID controller dynamics is not the best way to cope with the above-mentioned process characteristics of a waste incinerator.

HIGH-LEVEL CONTROL OF WTE PLANTS

The key to increasing the efficiency of WtE plants is to obtain a more stable operation, independent of the actual waste quality, the boiler cleaning status and other bottlenecks appearing during the various stages of the WtE plant operation.

High-level control must therefore include features normally applied by the best trained and experienced operators such as:

- Fast reactions, without overreacting, to cope with the fluctuations in the waste composition and to avoid capacity loss
- Waiting time after an adjustment to allow for the process to respond before a new control action
- Dynamic behavior adaptation to the current state of the process by focusing on the most important issues first.

Experience from more than twenty (20) years of working with high-level control shows that one of the most critical tasks is to divide the overall control strategy into subgroups; each subgroup will have a special task, which will be activated when needed. This function implies three (3) critical elements:

- Activation: initiation of the relevant control strategy - subgroup - i.e. it detects that a situation has occurred where this particular control strategy is needed.
- Control active: execute the special controls related to the selected active control strategy – subgroup.
- Deactivation, i.e. it detects that a control strategy subgroup is no longer needed and can be deactivated.

The described way of operating a WtE plant is basically similar to how an experienced operator would react on a control problem.

In a WtE plant the process conditions vary over time. This is dependent on the waste composition, and the plants maintenance state etc. Therefore, it is crucial to design the high-level control system to cope efficiently with these variations.

PRACTICAL IMPLEMENTATION

Based on decades of practical work with control of waste incinerators, Denmark-based Dublix Engineering A/S has developed a control scheme (FuzEvent®) that fulfils the above-mentioned requirements for the optimization of waste incinerators.

Main Principles:

The control strategy is based on rules that are derived from the expertise of process engineers and process operators.

The control dynamics are derived from manual control of the process in terms of waiting for the process to respond to previous adjustments, including consideration of other available historical plant process information.

The starting point for an optimization project is always a careful evaluation of the actual conditions at the WtE plant in question. The management of the WtE plant normally requests measurable performance improvements, which shall be clearly documented after the implementation of the high-level control scheme.

Typical performance guarantees with high-level control:

- Stability improvement in steam flow by 25-30%.
- Increased steam production of 4-5%
- Run factor at 90% with the high-level control system handling the process: e.g. controlling the set points to the PID loop controllers or direct control of the control outputs.

Other performance guarantees can be defined such as:

- 50% fewer violations of 850 degC (1562 degF) for 2 seconds limitations and less use of oil/gas burners to keep the temperatures above the required level.
- 50% less CO emission violation of the environmental limits.

Some plants want an increase to the plant capacity (energy production or amount of waste handled) but as it can be difficult to carry out an online registration of the waste quality, the above mentioned performance factors are more useful in a practical implementation.

Stability is typically measured as the daily standard deviation of the steam production, which is calculated on the basis of one minute average values. In other words, one minute average values of the steam production are saved, and the daily standard deviation is calculated from the 1440 1-minute average steam production values.

A reference period of one week is established prior to the activation of the high-level control system. During this reference period the average daily standard deviation STD_{Ref} and optionally the daily steam production $PROD_{Ref}$ are calculated as described above. After commissioning of the high-level control system, a one week test is carried out where the furnaces are controlled by the high-level FuzEvent control system, and where the daily standard deviation STD_{Fuz} and the daily steam production $PROD_{Fuz}$ are calculated in the same way as for the reference period.

The guarantees for 25% more stable steam flow and 4% more steam flow are calculated as:

$$\mathbf{STD_{Fuz} \leq 0.75 * STD_{Ref}}$$

$$\mathbf{PROD_{Fuz} \geq 1.04 * PROD_{Reef}}$$

Common control problems:

Figure 2 below shows a typical control problem, describing a situation with risk of overfilling the furnace followed by a risk of too high steam flow.

The white trend curve shows the steam flow (the steam flow set point for this boiler is set to sixty-eight (68) ton/hour). The steam flow is going down around 6:25 for approx. 20 minutes, and then around 6:40 the steam flow increases rapidly. The O_2 - the yellow curve - is decreasing around 6:40. The waste feed - the blue curve - is increasing until 6:40. Around 7:00 very high steam flow level appears.

In the described case the operator follows the situation carefully and before the plant actually trips he makes the right decisions; the straight lines in the blue curve indicate that the PID controller for waste feeding is forced to operate in manual. The manual control continues from 6:40 until approx. 7:40. It can be seen from this curve, that the operator makes 2 or 3 manual adjustments to the fuel feed during this period.

Figure 2, typical control problem

The above example shows one of the key problems with the existing PID control algorithms; in order to handle such complex control tasks it is necessary for the operator to follow the trend curves for: steam, O2 and the waste feeding for longer periods, in order to make the right decisions. A PID controller is normally handling short term process variations and not the type of control problems as described above.

A high-level FuzEvent control scheme can be set up in order to avoid such control problems.

The data analysis algorithm in the high-level control, based on FuzEvent for coping with difficult waste has an algorithm that utilizes historical data storage and data analysis of O_2, steam flow, furnace temperature, pressure drop over the grate and feeding of waste in order to detect changes in the calorific value of the waste. For this example it is relevant to use this algorithm to detect difficult waste by comparing the different data over a period of for instance 45 minutes. The algorithm defines a certain pattern of the above-mentioned information for detection of wet waste. If wet waste is detected, FuzEvent automatically takes proper action in due time by e.g. reducing the waste feed, adjustments to the primary air flow etc. basically in the same way as an experienced operator would do.

The advantage of high level control is that it provides solutions that react automatically and consistently. This is not the case for manual control with 5 different operators.

The high-level control structure

Figure 3 below shows a typical overall control structure with multiple inputs and outputs for the different defined control strategies in a high-level control system.

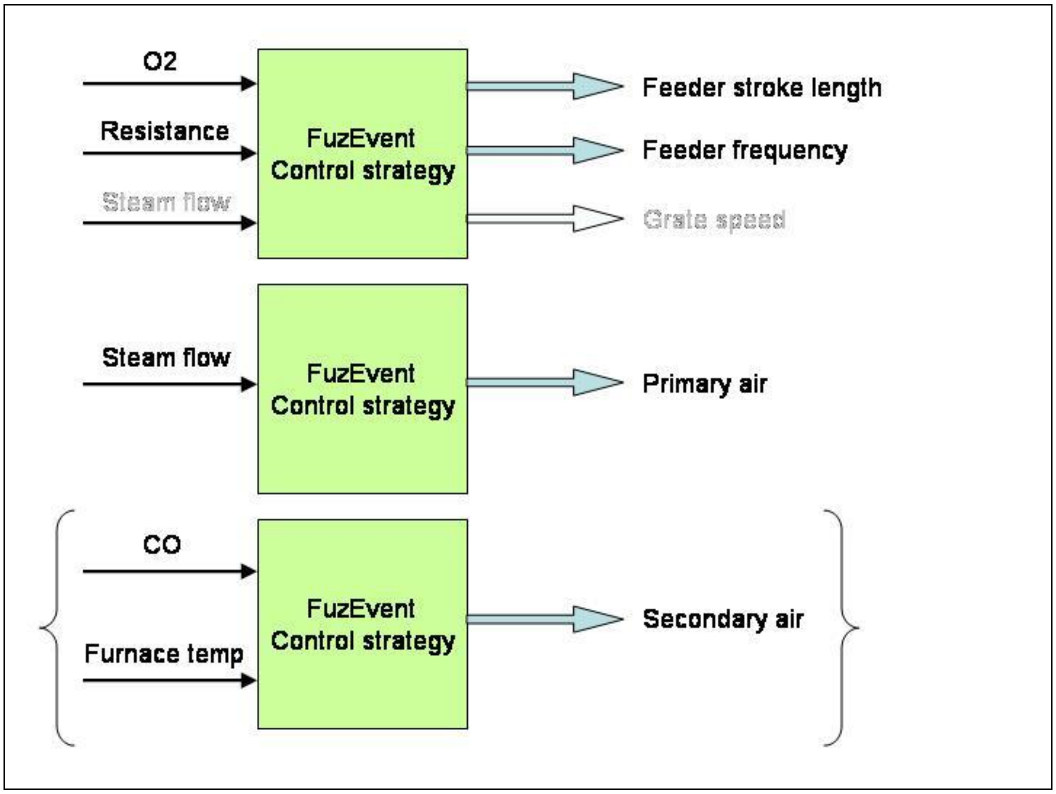

Figure 3, typical control structure

In order to establish such control structures for online operating systems, various graphical displays is available. Figure 4 shows a detailed display indicating the various control strategies also called EventX defined for a specific WtE furnace.

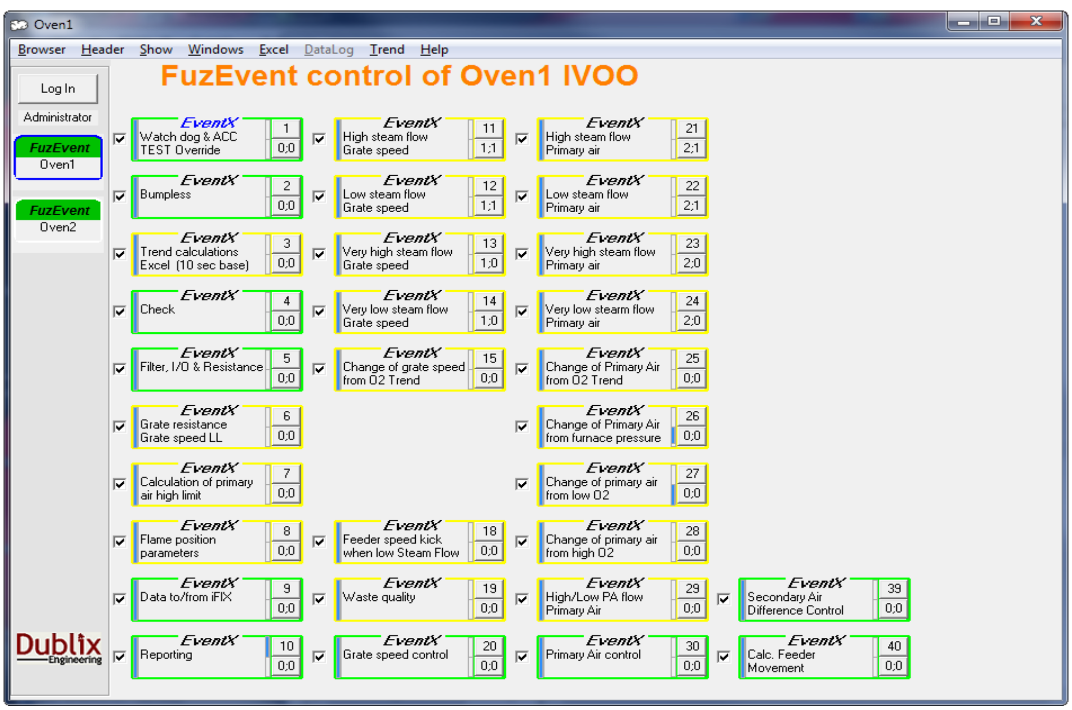

Figure 4, EventX graphical control display

Behind each EventX element, specific control strategies have been defined for handling different control problems. Each EventX has a descriptive name indicating the function; the numbers in the right top corner indicate the priority group to which the EventX belongs; the colors and the bars filled or not filled out for each EventX box show if the actual control strategy is currently solving a problem or waiting to activate.

Each EventX has a set of properties the so-called FECA (FECA-FuzEvent Control Application) properties, which can be seen in the below figure 5.

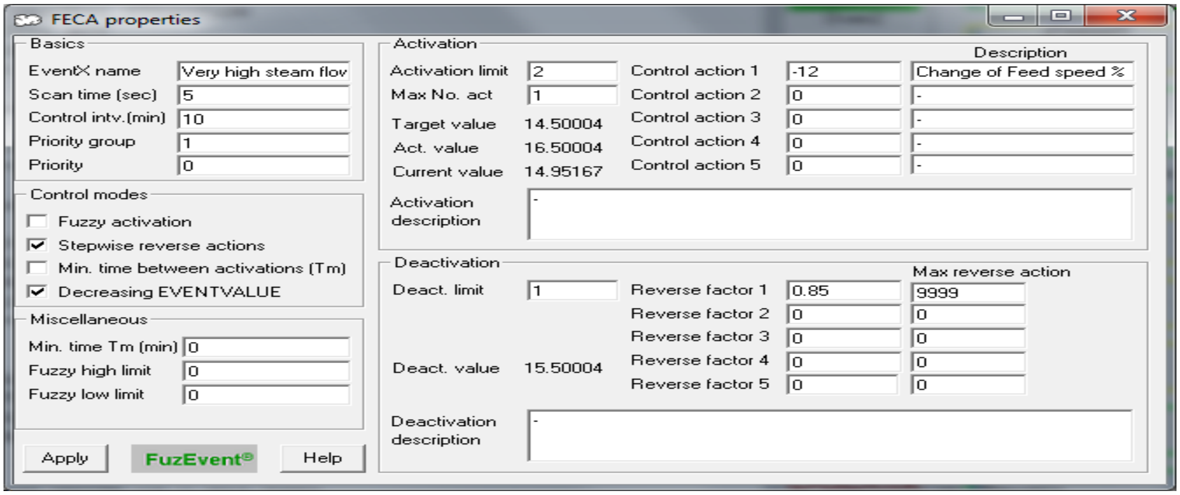

Figure 5, FECA Properties

The implementation of a high-level control must not influence the existing control system structure. This is important as the normal control system will take care of: alarm handling, safety shutdown functions and basic control loops. These functions must remain unchanged after the implementation of a high-level control optimization system.

The high-level control system can be partly or totally disconnected if the operator considers the functions decrease the plant performance, or if the operator disagrees with the actions activated by the high-level control system. During the commissioning of the system this can happen often; later in the stable operating period operator initiated switch-off of the FuzEvent system only happens in very special situations.

During periods without the high-level control system in operation, the normal control system will operate the plant exactly as prior to the installation of the high-level control system.

An automatic watch dog function ensures that the high-level control is healthy. In case of malfunctions, the high-level control system will automatically be switched off.

Figure 6 below shows a typical structure of a high-level control system integrated into the existing conventional control system.

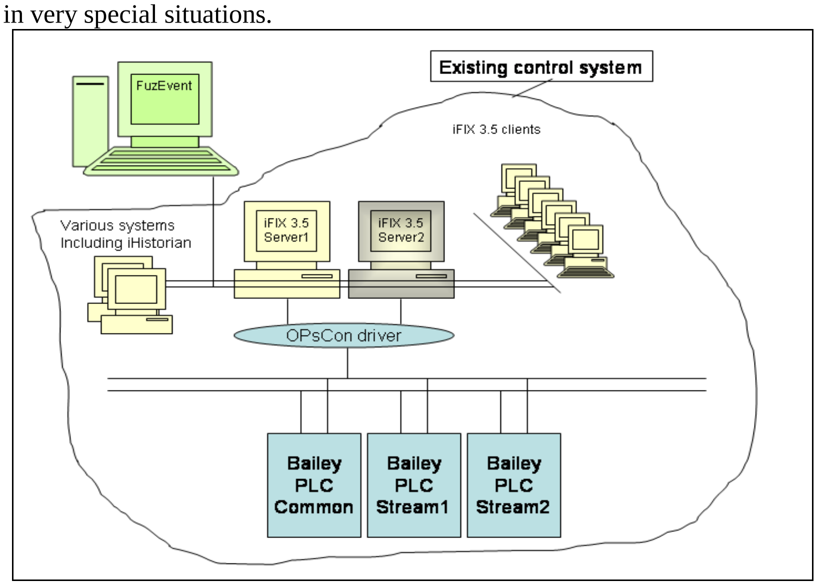

Figure 6, typical control system configuration with high level control

CONCLUSION

Practical results of high-level control of WtE plants:

The below figure 7 shows the final result from the Veolia Tyseley UK plant after the implementation of the FuzEvent system on two combustion lines. This is showing the same trend curves as shown previously (Figure 2) and also attached in small to the right below:

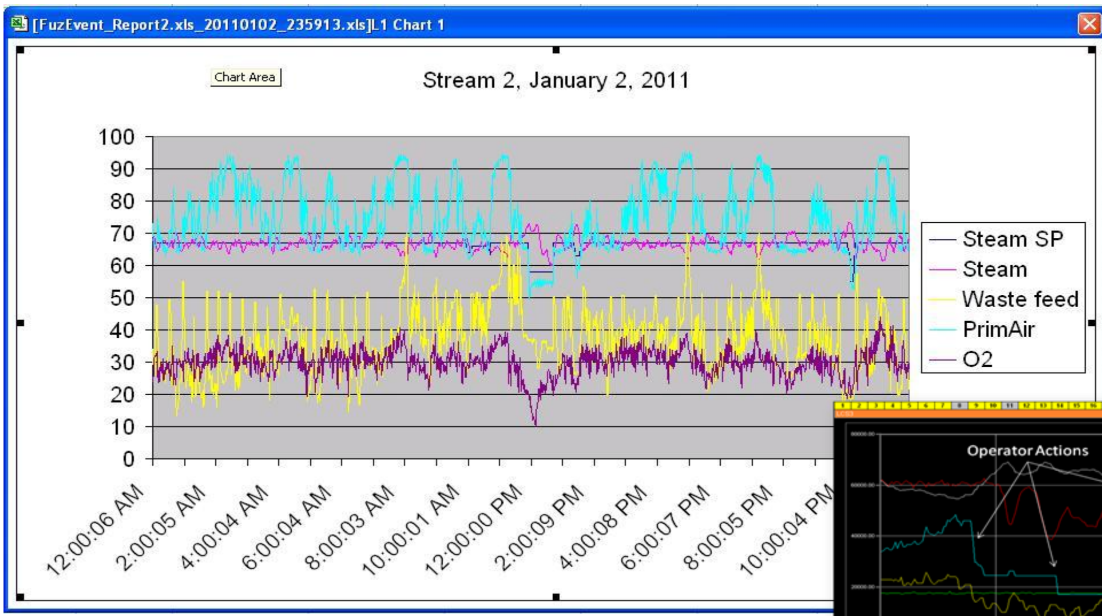

Figure 7, operating with high level FuzEvent.

Operating without high level FuzEvent

Scales on the axes:

Steam Set Point and Steam y-axe:	[0-100] t/h
Waste feed y-axe:	[0-100]%
Primary Air y-axe:	[0-100000] m3/h
O_2 y-axe:	[0-20]%

After the high-level controls were implemented the boiler became 50% more stable. The standard deviation on steam flow is 1.90 t/h, or 50% less, than it was prior to the new high-level controls were installed.

The WtE plants operating in Europe and China are following a strict set of environmental legislation defining: combustion temperatures, emission levels and quality of the residual products. The implementation of a high-level control will always be based on the condition that environmental requirements can be maintained or improved.

Due to the functional separation of the existing control system and the high-level control system the implementation of a high-level FuzEvent system is fast and can easily be modified and adjusted while the plant is in full operation. The implementation period is normally less than 4 months.

The cost effectiveness of high-level control can be very high; typical figures are:

- 4-7% increase of the steam production due to a higher steam flow set point and lower excess O2.
- 5-10% more waste treatment capacity due to a constantly high combustion efficiency and better slag burn out quality.
- 50-70% less operator intervention and release of operator attention for other duties.
- 50% less use of utility burner start-up (in case of too low temperatures in the combustion chamber) on some plants this can annually save many thousands liters of oil or gas. The ROI (Return Of Investment) of high level control will typically be less than twelve (12) months.

A practical way of constant measurement of the performance is to provide on-line calculated Key Performance Indicators (KPIs) to be displayed in the control room these are;

- Run-factor of the high level control being in control of the process, showing the acceptance from the operators.
- Steam flow stability based on calculated standard deviation.
- Average O2 level

The below Table 1, shows some KPIs showing the stability improvement and the run-factor for twelve (12) WtE plants operating 24 WtE combustion lines with the FuzEvent high-level control system installed.

Plant name (building year) Country	Operator (owner)	Description Ton waste/hour	Results of installation	Service contract	FuzEvent Operating	KPI Run-factor with FuzEvent
Köping, WtE plant Built 1972, Sweden	Vafab Miljö AB (Public)	One Kockum grate, 5 t/h household aste	More stable operation, CO reduction	Yes	2004-ongoing	Run-factor >98%
Hallingdal, WtE plant Built 1985 Norway	Hallingdal Renovasjon IS (Public)	One 3.5 t/h household waste BWV grate	10% increase in waste throughput	Yes	2005-ongoing	Run-factor 100%
AVR Rozenburg, WtE Built 1972 Netherlands	van Gansewinkel Groep (Private)	Three Babcock Roller grate, 25 t/h household waste	>50% more stable steam flow	No	2007- 2010	Currently not in operation due to plant revamping
Houthalen, WtE Built 1984 Belgium	Bionerga (Public)	Two 8.5 t/h household waste, BWV grate with rotating kiln	More stable steam flow, 4% more steam production	Yes	2007-ongoing	Run-factor >95% 4% increased steam production
IBW Virginal, WtE plant Built 2004, Belgium	IBW Virginal (Public)	One household waste Stiefel water cooled grate.	Combustion of very low calorific waste. More stable steam production	Yes	2007-ongoing	Run-factor >90%
IVM Eeklo, WtE plant Built 1991 Belgium	IVM Eeklo (Public)	Two 8.5 t/h household waste, BWV grate with rotating kiln	More stable combustion, >30% more stable steam production.	Yes	2008-ongoing	Run-factor >90% Stability increase>35%
STVL Limoges, WtE Built 1985 France	Veolia FR (Private)	Three lines*5 t/h household waste BWV (Vølund grate)	Increased waste treatment capacity >12-24%	No	2008- ongoing	Run-factor >98% Increased waste treatment capacity>15 %
Tyseley EfW Built 1995 UK	Veolia UK (Private)	Two lines Steinmüller grates of a 25 ton/hour waste capacity each	>50% steam flow stability	Yes	2009-ongoing	Run-factor >98% Stability increase>50%
Mataro, WtE plant Built 1994 Spain	Veolia (Public)	Two Martin combustion grates each 19 t/hour waste	Target: burning of high calorific waste (11,7 MJ/kg)	No	2011-ongoing	Run-factor >98%
Sita Tees Valley EfW Plant Built 1998 UK	Sita UK (private)	Two former BWV Grate Combustion lines, now Saretco SAR 3 grate based, each 14 t/h waste	Target; more stable operation	No	2010 In commissioning	Pending a major revamping of the plant
IVOO WtE plant Built 1982 Belgium	Intergemeentelijke Vereniging voor het afvalbeheer voor Oostende en Ommeland	Two Sehgers lines from 1982 each having a capacity of 5,5 t waste/hour	More stable combustion, >36% more stable steam production.	Yes	2011-ongoing	Run-factor >98% Stability increase>36%
Huancheng WtE plant Built ? Shanghai China	Veolia China	FuzEvent operating one combustion line operating Steinmüller grates,	More stable combustion, >30% more stable steam production. Run Factor >90%	No	January 2012 completed commissioning	Pending Performance test March 2012

Table 1, Results of high-level control at 12 plants in Europe and China