Guidelines for the Conversion of Solid Fuel Boilers from Coal to Wood Pellet Firing

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Contents

About this guide

1. The compilation of this Technical Guide has been facilitated by the Bioenergy Association of New Zealand (BANZ) and the Energy Efficiency and Conservation Authority (EECA).
2. It is an outcome of an industry discussion and collaboration. It captures the collective technical knowledge of the following consultants: Solid Energy, Taymac Engineering, Mechserve Heating and Ventilating, Powell Fenwick Consultants, Opus International and Scion. It represents their collective technical experience in the conversion of solid fuel boilers to burn wood pellets and is based on three years operating experience. In addition, it benefits from the collective experience of the Members of the BANZ Wood Fuel and Wood Pellet Interest Groups.

3. This guide is provided in good faith as an addition to the ongoing body of knowledge relating to the combustion of wood fuels. However, none of those involved with its preparation accept any liability either for the information contained herein, or its application.
4. This guide is not a design manual. Those involved with the conversion of boilers from coal to wood pellet firing should be competent in boiler design and conversant with combustion and boiler operation.
5. As with all BANZ technical guidance documents, this guide is a 'living document' and will be revised from time to time and reissued, as new information comes to our attention. If you have suggested additions to this guide please contact admin@bioenergy.org.nz

1. Introduction

This Technical Guide is intended to provide guidance on the conversion of existing coal fired boilers to wood pellet operation. The number of boilers running on wood pellets in New Zealand (particularly in schools) continues to rise, as does the number of organisations offering installation and conversion services. It is essential that the lessons from early conversions are used to help inform this growing industry.

There are a number of obvious advantages to using wood pellets, the most obvious being that they are a completely renewable fuel, and are relatively clean burning.

Of paramount importance in any conversion is the need not simply to maintain the safety and integrity of the boiler and its control systems, but to improve safety to the level of 'best practice'.

The second most important issue is that the boiler's combustion efficiency after conversion should be at least as good as before conversion, and preferably improved, along with emissions from the boiler of carbon monoxide (CO) and particulates (PM_{10}'s). In a conversion, while this is not guaranteed, an improvement can be observed as part of a properly performed conversion.

Although based primarily on sectional boilers with underfeed stokers, this Guide can, with care, be used as a basis for conversion of most boiler and stoker types. The essential operational and safety issues are similar. Likewise, although this Guide has been formulated on the basis of experience with wood pellet firing, it can with care, be used in relation to firing dry wood chip.

2. Background

The Bioenergy Association of New Zealand (BANZ) wishes to ensure that all boilers being converted from coal to run on wood pellets are installed for safe operation, are trouble free, and operate as efficiently as possible.

BANZ Technical Guides are not replacements for design manuals, or designed to train those not familiar with combustion and boiler operation. The Guides are intended to supplement proper design manuals and professional training by ensuring that current best practice is communicated to those undertaking bioenergy projects.

This Guide aims to provide information at a level appropriate to both designers and operators and is a mix of both technical and more general information. With the conversion of existing boilers to wood pellet operation there is a particular need to support boiler operators who often lack formal boiler training. This Guide includes information for boiler operators. It is particularly of concern for school or other small scale users where a caretaker or plant owner looks after the boiler amongst a number of other responsibilities. Some operators are well informed, others less well so.

The Guide also covers both aspects that relate to conversion design, and the operation of the boiler. It has a particular emphasis on the differences between a boiler running on wood pellets and one on coal. The specific best practice information is supported by photos and diagrams where possible to illustrate the various points.

The Guide, although directed specifically at pellets, is equally applicable (and should be applied) to all dry solid wood fuel firing.

3. Key differences between Coal and Wood Pellet Fuels

Table 1 sets out a number of key characteristics of coal and wood pellet fuels. These characteristics may warrant particular attention when undertaking a conversion.

Table 1: Different characteristics of coal and wood pellet fuel.

Parameter	Coal	Wood Pellets
Volatile matter on a dry ash free basis	~47%	~85%
Air recommended for efficient combustion	Predominantly underfire air	Predominantly overfire (secondary) air
Calorific value (gross)	21-30 MJ/kg Wood pellets have a lower energy density than coal. A greater volume needs to be stored and used to provide the same amount of heat.	19 MJ/kg
Bulk density	850 kg/m^3 (1)	650 kg/m^3
Environmental benefits	Wood pellets are a renewable fuel made from wood residue. They are considered neutral with respect to greenhouse gas emissions. Compared to all fuel alternatives, wood pellets provide the greatest reduction in CO_2 emissions. Particulate emissions are also greatly reduced because wood pellet fuel inherently has very low moisture and ash content.[2]	
Ash	4-6%	0.5-0.8%
Sulphur	0.3 – 1.5%	negligible

4. Key Issues to Consider in Coal to Pellets Boiler Conversions

This section provides details on the key issues to consider in the conversion of coal fired boilers to wood pellets. Conversions may involve the installation of a new coal fired boiler bought as part of a conversion project, or the conversion of an existing coal boiler to run on pellets. While the issues are the same, more modern coal boilers already have incorporated in their construction a number of features which make their conversion considerably easier than older units.

Coal and wood pellets are both solid fuels. Typically the boiler will already have two of the critical components needed for burning wood pellets:

[1] http://hypertextbook.com/facts/2003/JuliyaFisher.shtml

[2] Note – this is only true when the boiler is working correctly. The fuel is not the only controlling factor here.

1. ***Fuel storage***, often in a ***bunker*** or ***hopper***. Solid fuels need to be stored on site. They cannot be reticulated like electricity or gas. It is essential that wood pellets are kept dry. In the presence of moisture they rapidly expand and disintegrate. A pellet hopper or bunker must be moisture proof, both from direct moisture such as rain, as well as general dampness. It is recommended that existing concrete coal bunkers are lined with wood or steel to ensure no absorption of moisture from the concrete.
   It is essential that the floor of a bunker is angled towards the fuel feed auger at an angle of at least 40^0 to ensure the complete delivery of all fuel in the bunker to the boiler. This angle can be reduced if a smooth material is used. There should be no 'dead spots'.

   If there is even the slightest possibility of water ingress into the boiler house (very important for those boiler houses below ground), the boiler house should be fitted with a sump pump (in a readily accessible position) with an alarm to warn of its failure. Water accumulation in the boiler house can seep into the pellet bunker and feed auger causing pellet expansion and potential blockages.

2. A ***fuel delivery mechanism*** designed to move the solid fuel automatically from the fuel storage to the boiler. A rotating auger is used (otherwise known as an auto-stoker or stoker screw). The rate of fuel delivery is controlled by the speed of the auger.

Although every conversion is different, there are a number of recommended steps to ensure the best outcome.

4.1 Burn Back Protection

Burn back protection (also known as a fire safety anti-burnback system), should be installed if the boiler combustion chamber is directly connected to either a small day hopper or the main fuel bunker. There is a risk in some circumstances that the fire in the boiler will burn back along the auger screw towards the bunker. In some solid-fuel boiler designs this is avoided by using a rotary valve and a break in the fuel feed path between two separate augers which breaks the direct physical path between the boiler and fuel bunker. The use of two augers should be considered 'best practice'. Any other solution, whilst adequate, is slightly less optimal. If the boiler does not have a rotary valve a fail-safe electronic system can be installed which extinguishes the fire in the fuel feed mechanism if excessive heat is detected.

The boiler stoker auger should be provided with two levels of ***burn back protection***:

1. The first is normally in the form of a ***temperature probe*** on the outside of the auger tube. If a burn back is detected the control system turns the auger on and feeds the burning material safely into the combustion chamber.
2. The second level of protection can be a ***quencher.*** This is a reserve of water connected via a valve to the auger tube which is activated by a second temperature detector sufficiently far back along the auger tube so that it will not activate until well after the first burn back protection.

The quencher should have a self-contained water supply (i.e. not reliant on mains water pressure) and should either require no electricity to operate, or have an uninterruptable power supply to ensure operation in the event of mains failure. Such a quencher must be fitted with a test button to prove its operation. Because a full test necessarily involves opening the control valve which admits water to the auger tube, an isolation valve must be fitted between the quencher valve and the auger to prevent the inadvertent admission of water to the tube. This additional valve MUST be locked in the open position at all times and an easily visible reminder to the operator placed on the front of the operating panel to do so.

3. An alternative to a quencher is to connect the output from the second temperature detector to a 24-hour continuously monitored fire detection system, which will activate an alarm if an apparent burn-back is detected.

4.2 Boiler Water Level and Pressure Relief

The boiler water pressure safety devices should be tested and relief pressures verified if necessary. There should be either:

1. An open vent pipe from each boiler to the system header tank, or
2. A correctly rated and correctly set up expansion vessel, and safety valve fitted on each boiler.
3. Water level in vent pipe or expansion vessel must be monitored visually or by level switch
4. Make up water supply must be tested and loss of supply alarmed.

Note - it MUST be impossible to isolate the boiler from the vent or the safety valve.

(Boiler water side pressure is not an issue specific to conversions, but remains the same irrespective of the fuel used. Its inclusion here is by way of reminder.)

4.3 Boiler Water Temperature

1. Check that the boiler control temperature thermostat is set at an appropriate temperature (typically 70-80^{o}C). Beware that lower temperatures lead to internal corrosion and premature failure of the boiler. They are not recommended.
2. Check that the boiler high-limit temperature thermostat is set at an appropriate temperature (typically 80-90^{o}C). This is a safety device and should be hard-wired to stop both the stoker auger and stoker fan in the event of over temperature.

(Boiler temperature is not an issue specific to conversions but remains the same irrespective of the fuel used. Its inclusion here is by way of reminder.)

4.4 Boiler Control Systems

1. The boiler control system MUST include ***airflow verification*** by means of an air pressure switch or the like.

2. The boiler control system MUST include ***ignition verification*** by means of stack or retort temperature measurement or the like.

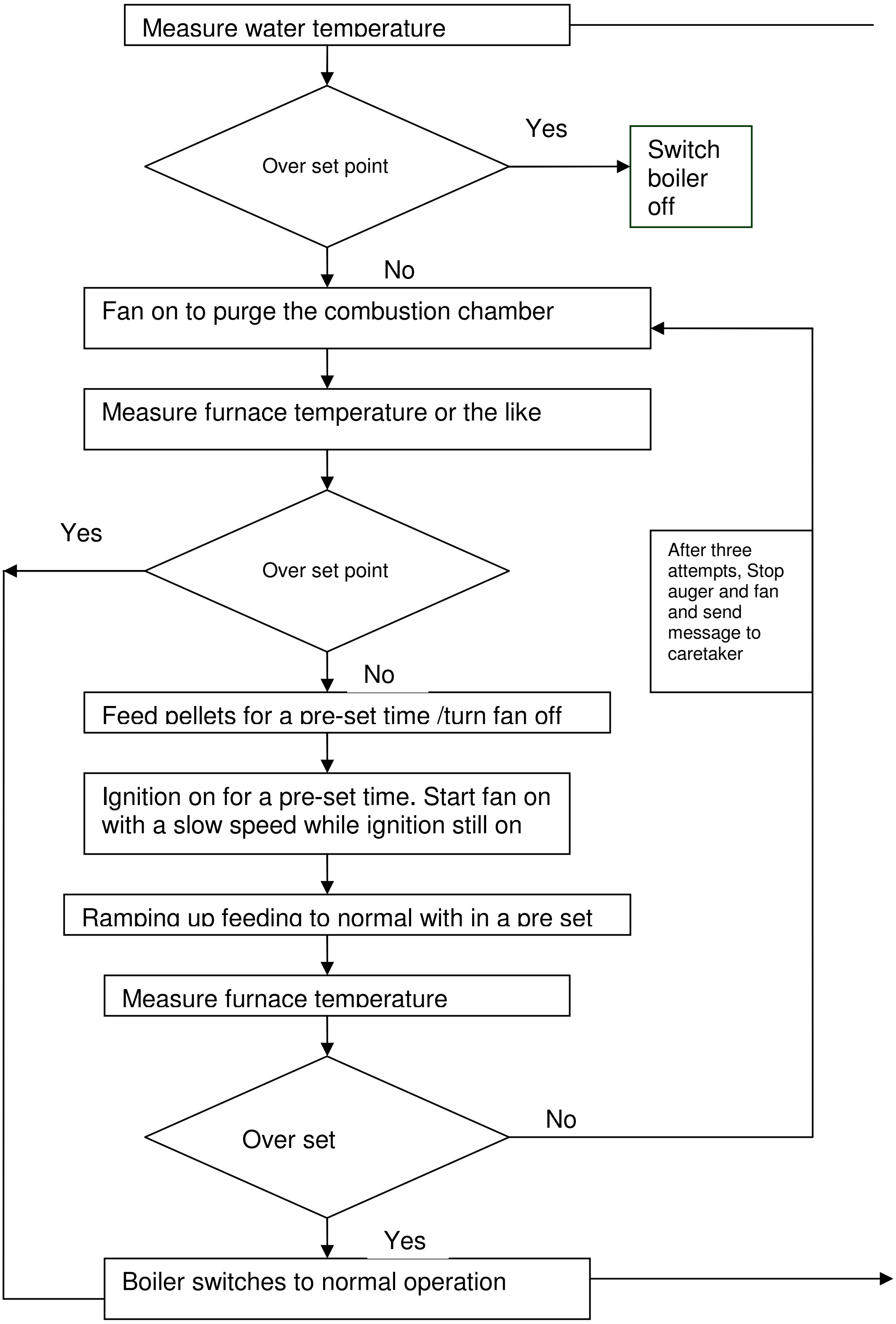
Due to the high levels of volatiles contained in wood pellets, large ‘piles’ of smouldering fuel MUST be avoided. Piles of poorly combusted wood pellets create large volumes of flammable gases. Ignition and airflow verification ensure that the fire is burning correctly before adding more fuel.

Correct start-up is critical to ensuring safe boiler operation.

1. For the system fitted with automatic ignition, the following flow chart (see *Figure 1*) should be used when defining the start-up sequence for the boiler control system after conversion.

Figure 1: Start Up Sequence – flow chart- with auto ignition

The start up sequence should be:



2. For the system with kindling control:

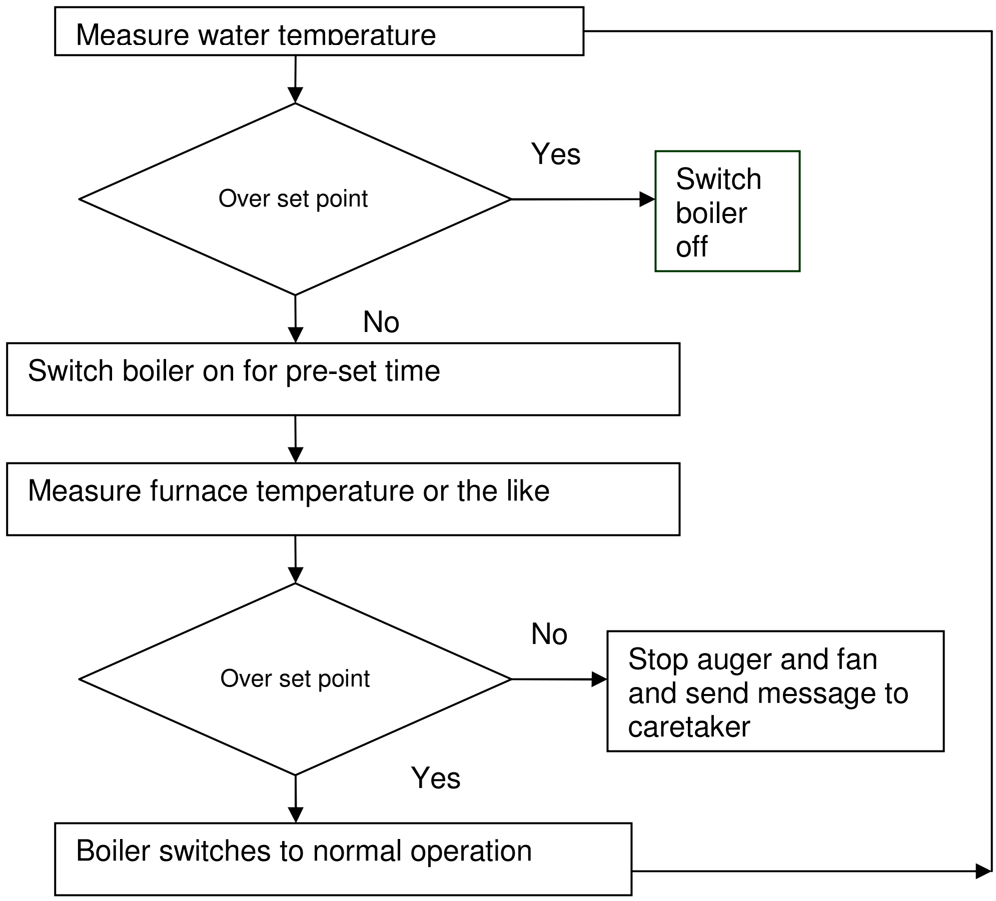


Figure 2: Start Up Sequence – flow chart – with kindling control

4.5 Stoker / Auger

Continuous feeding is preferred. The stoker auger should be provided with a ***VFD or VSD [variable frequency/speed drive]*** or other means to ensure a continuous feed rate of pellets. This should be calibrated to ensure that at 100% boiler output the auger is not supplying excess fuel.

The stoker ***FD [forced draft] fan*** should be provided with a VFD/VSD or adjustable damper. It should provide a suitable airflow and air distribution for the auger fuel feed. If oxygen control[3] is provided then this should be for 'fine trim' only, not as a means of primary control.

[3] Oxygen control is a means of regulating combustion by way of an oxygen sensor that would raise or lower the fan speed a little, so that (on average), excess oxygen is minimized in the flue gasses.

Secondary or 'overfire' air is critical for the efficient combustion of wood pellets. The secondary air nozzles should be positioned to provide efficient and rapid mixing with the combustible gases coming off the fire. Typically, in many boilers the most effective way of achieving this is by arranging the overfire/secondary air nozzles in a tangential format, to encourage a vortex of air above the fire.

4.6 Ignition

4.6.1 Auto electric ignition

Where the boiler is fitted with an automatic electric ignition, the stoker fan should be set to provide air at a reduced speed during and after ignition, increasing slowly in speed once ignition is established, to the normal operating speed.

Benefits of an electric ignition system include:

- It eliminates the need to constantly keep a fire in the grate using a kindle cycle. Boilers no longer need to keep on a very low fire over nights, weekends, and holidays, but can come on when needed.
- The boiler internals stay cleaner.
- There is no need to light a boiler conventionally. Ignition is just as convenient as gas or oil.

Note – while this Guidance Document focuses on wood pellets we note at the outset its relevance to wood chip fuel. Electronic ignition can only be used on fuels up to 35% moisture content. Greater than 35% require fossil fuel ignition.

4.6.2 Boiler operation without auto ignition

Wood pellets will always burn back or burn down faster than coal once the combustion air and fuel feed are stopped. For this reason the wood pellets will more often than not burn back along the stoker screw until either possibly going out or reaching the main fuel bunker. Ideally the combustion of a solid fuel is best kept in the grate area as it is designed for high temperatures.

Set up for kindle and overnight kindle mode.

1. Run boiler on normal heat output setting.
2. Stop boiler and allow the fuel bed to retreat into the grate whilst recording the time taken to do so.
3. Make sure that the fuel bed does not drop low enough to expose the stoker screw.
4. Return boiler to normal heating mode and make sure that fire builds effectively.
5. Some boilers burn back faster than others. 5 minutes of fuel and air (combustion) to 2 hours of no fuel and air (kindle) is a good starting position.

This system maintains safe operation of the boiler and reduces the chance of a gasification explosion. The fuel used to maintain the fire is not wasted as it is still putting heat into the boiler.

4.7 Air flow to support effective combustion

Wood pellets require considerably more secondary air for completed combustion than coal. Very old coal stokers only supply air from beneath the fuel bed.

Many coal boilers have both underfire air (as described above) and additional 'overfire' air injected into the space immediately above the fuel bed to ensure the completed burn out of the combustible gases and particulates.

A small amount of air is also forced along the stoker screw towards the combustion chamber in order to reduce smoke back-feeding up through the day hopper.

The issue faced in conversion is that to get proper combustion of wood pellets requires considerably less underfire, and considerably more overfire air. Some stoker designs can accommodate this change in air requirements with a simple adjustment of the air dampers, but some cannot. In the case of those which cannot, there are generally three alternatives:

1. Replace the entire stoker with a modern unit.
2. Modify the overfire air ducting to provide more air; or
3. Install an additional fan, ducting and often secondary air nozzles to provide the necessary air.

All three approaches have been used and can produce a satisfactory conversion. However, each requires competent engineering with a good understanding of the combustion process.

4.7.1 Grate refinements

Poor combustion can be a problem with conversions when an old style coal grate is in place (see *Figure 3*). It can lead to a volcano effect with high-temperature, small combustion zones, and airborne pellets, due to the lower level air feeding positions and lack of overfire air.

Note - a standard coal grate and air distribution is <u>not a conversion.</u>

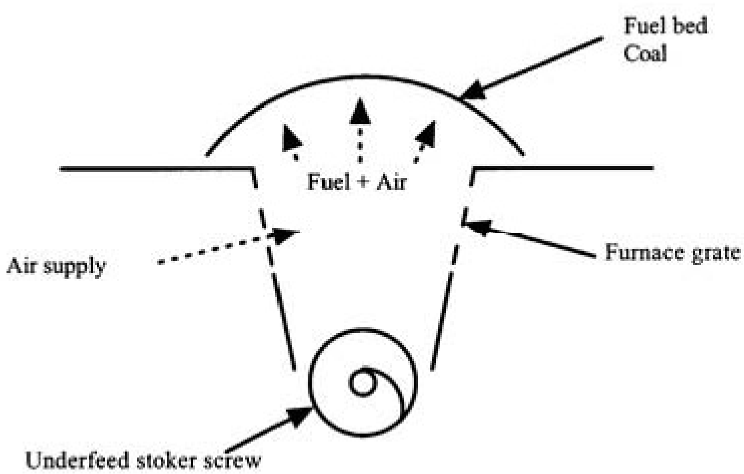


***Figure 3*: Schematic of standard coal grate**[4]

Ideally the combustion of wood pellets should primarily take place on the outer slopes of the fire grate, and this is where the underfire air should be focussed. Too much air in the retort can lead to the volcano effect with a high temperature and small combustion zone and airborne pellets.

Although it is possible to retrofit a new grate into a boiler, serious consideration should be given to install a new specifically designed stoker with separate primary and secondary air controls and a well designed grate for burning wood pellets

***Figure 4*: Schematic of recommended pellet grate**

4.8 Operation Manual

Smaller boilers are often operated by untrained people, for whom administering the boiler is an add-on to their main job. The supplier of a new boiler should assume that the person trained at the time of installation will not continue to be the operator, or that at times when they are not available others will be asked to operate the boiler. For safety and protection of the plant it is essential that the boiler supplier provide good, easy-to-read manuals and instructions. These MUST be written so that a person untrained in boiler operation could operate the boiler safely and efficiently.

Not only must the operating manual cover all normal boiler operating situations, it must be specifically written for the particular installation, taking into account the methods used for control, heat distribution, and safety. A generic boiler manual is inadequate.

It is good practice to provide checklists and quick guides which can be affixed to the boilerhouse wall for ready reference. It is also essential that the emergency contact details of the boiler supplier and / or installer be affixed in a prominent location inside the boilerhouse.

[4] 'Sustainable Fuel for Schools – Pelletised Wood Replaces Coal', George Estcourt, Scion http://www.wasteminz.org.nz/conference/conferencepapers2006/George%20Estcourt.pdf

4.9 *Operator Training*[5]

After the installation of a new boiler or the conversion of an existing boiler to wood pellets, the operator should be provided with training on the new installation and be provided with a suitable written manual for operation and basic maintenance. A practical training course is recommended for the operator.

Key issues that operator training should cover include:

- ***Boiler Conversion and Basic Operation Principles*** – General overview of what owners and operators need to understand are the different characteristics between using coal or wood pellet fuels.

- ***Boiler Output Optimisation*** - Optimising the performance of a boiler reduces running costs and improves site operations. The operator must understand how the wood pellet boiler has been tuned (typically this is by the experts undertaking the conversion and MUST be carried out using appropriate flue gas analysis equipment) to maximize efficiency and heat delivery, particularly with respect to different control settings, fuel feed speed, and air supply. Once the boiler has been tuned it should not be tampered with. If there are issues which need to be addressed, the operator is best advised to call in an expert with the appropriate equipment. It must be emphasised that while a visual check of combustion conditions can give apparently satisfactory results, there is no substitute for doing it with the correct gas analysis equipment, and the end result can improve combustion efficiency by several per cent and improve the emissions profile for CO and PM_{10}.

While the physical modifications and boiler design are the main contributors to efficiency, as a simple rule of thumb, if the CO levels are low then the pellets are being burned correctly and the relative levels of efficiency will follow. If the CO levels are high then unburnt fuel (in the form of a combustible gas) will be coming out of the flue and the efficiency, will be, by default, low.

- ***Combustion Characteristics of Wood Pellets -*** Burning pellets is somewhat different to burning coal and the following issues should be considered:

  - Volatiles and their release from pellet burning relative to coal
  - Auger delivery speed
  - How to regulate air flows
  - Fire beds – what they should look like.

- ***Basic Boiler Maintenance*** - basic boiler maintenance is essential for safe and efficient burning. Key information that operators should be aware of include:
  - Fuel feeding system
  - Annual maintenance
  - Air duct cleaning
  - Tube cleaning
  - Ash removal

[5] For further details on Wood Pellet Boiler Operator Training Courses check www.woodpellets.org.nz/training.asp

  - Heating surface cleaning
  - Running the pellets out if there is a long non-use period, such as over the summer.

- ***Safety Devices*** – the safe operation of the system is paramount, and all safety devices must be regularly tested and calibrated to ensure their proper operation.

4.10 Boiler Efficiency

A properly converted boiler should be at least as efficient as it was prior to the conversion, if not more efficient. In no case should boiler efficiency be reduced by conversion to wood pellet firing.

The essential boiler efficiency is a function of the boiler design, and there is little in a conversion to alter that design. However, there are a number of details in a conversion which if not carried out properly can have a negative impact.

Likewise, even a well converted boiler can fall well short of efficient operation if it is not set up and adjusted by a competent combustion specialist, equipped with the right instrumentation, and with the right experience of wood pellet combustion. This however is true of any boiler operating on any fuel.

Long term efficiency depends most of all on maintenance and housekeeping. To achieve this, it is essential to invest in proper operator training and to ensure there is adequate maintenance budget.

4.11 System Efficiency

There is little point in having an efficient boiler if the distribution system which it feeds, or the controls which govern the system are not of a similar standard in terms of efficiency.

System efficiency is often overlooked both during the initial planning stage, and post-conversion. Antiquated distribution and control systems can negate any efficiency gains that may be made. Operators should address their control and distribution systems as a part of a wider energy efficiency programme. Often, relatively small expenditure on controls in particular, can produce disproportionate benefits in both energy efficiency and comfort.

5. Operation

5.1 Maintenance

It is critical for safe and efficient operation of the wood pellet boiler that it is maintained according to the supplier’s instructions. A regular maintenance schedule should be established and clear records of the maintenance undertaken should be kept with the asset documents. Good record keeping is essential to ensure that appropriate maintenance is carried out when necessary.

It is recommended that the boiler owner undertake periodic audits to ensure that appropriate maintenance and operation is occurring so that no safety issues arise.

It is good operating practice to have a logbook in the boilerhouse in which all actions taken and observations made are logged, without exception. Such books can be an invaluable source of information later when trying to resolve problems.

5.2 Ash disposal

A few more sophisticated boilers are equipped with automatic ash removal systems. Most boilers however still require manual de-ashing.

It is important to remove ash regularly from the combustion chamber. It is equally important to remove the fine ash which accumulates inside the boiler gas passages. A relatively small accumulation of ash can lead to a significant loss of heat transfer efficiency. The containment of dusts and ashes is also a workplace health and safety issue.

Wood pellets produce 0.4% of their original weight in ash, compared to 5% for coal. Fifty tonnes of coal produces three tonnes of ash, enough to fill two skips. The equivalent ash from wood pellets is 0.22 tonnes or 220 kg.

The ash from wood pellets is commonly disposed of as a garden fertiliser.

6. Emissions

In many cases the prime reason to convert to pellets is the desire for reduced emissions. As in the case of efficiency, emissions from a properly converted boiler should be at least as good but ideally better than they were prior to the conversion. In no case should emissions be increased by conversion to wood pellet firing. As noted in earlier sections, in a properly converted and tuned system, CO levels should be lower (as a guide – 200 ppm would be considered a good result). If the CO levels are high then un-burnt fuel (in the form of a combustible gas) will be coming out of the flue. Tests indicate there is a relationship between higher CO and increased levels of particulates. As part of boiler testing, the tuning process will aim to achieve the best outcome in terms of efficiency and emissions. While not guaranteed, an improvement in both efficiency and emissions can be observed as part of a properly performed conversion.

7. Regulations

There are a number of safety regulations which the heat plant will need to meet. The heat plant conversion engineer should check these out as they apply to the current plant and in its modified state. In addition there will likely be a need for a Resource Consent from the Regional Council to address emissions to air. Requirements for consents will vary from Council to Council and may depend on the size of the installation.

Key regulations relating to boilers include the OSH publication "Boilers - Approved Code of Practice for the Design, Safe Operation, Maintenance and Servicing of".[6] This document applies if the temperature is above 100°C.

[6] http://www.osh.dol.govt.nz/order/catalogue/8.shtml

Below 100°C, which is where all low temperature hot water boilers are, the situation is less clear. Boilers must comply with the NZ unfired pressure vessel requirements (NZS 1841 for construction.) From the point of view of hazard analysis, they are classed as Hazard Level “E” by AS4343.

At this stage there are no regulations relating specifically to low temperature hot water boiler conversions.

8. References

1. http://hypertextbook.com/facts/2003/JuliyaFisher.shtml

2. ‘Sustainable Fuel for Schools – Pelletised Wood Replaces Coal’, George Estcourt, Scion http://www.wasteminz.org.nz/conference/conferencepapers2006/George%20Estcourt.pdf

3. www.woodpellets.org.nz/training.asp

4. “Boilers - Approved Code of Practice for the Design, Safe Operation, Maintenance and Servicing of” http://www.osh.dol.govt.nz/order/catalogue/8.shtml