FEBRUARY 2014

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# Evaluation of the effectiveness of the OekoTube ESP in the management of $PM_{10}$ in Reefton.

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# EXECUTIVE SUMMARY

This report evaluates the likely effectiveness of the OekoTube Electrostatic Precipitator (ESP) in reducing $PM_{10}$ concentrations in Reefton. Ambient air monitoring carried out by the West Coast Regional Council indicates that concentrations of $PM_{10}$ in Reefton currently exceed National Environmental Standards for Air Quality (NESAQ) (50 µg $m^{-3}$, 24-hour average, one allowable exceedence per year) regularly each winter. Compliance with the NES is required by September 2020 and an interim target of three exceedences must be met by 2016. A 56% reduction in $PM_{10}$ concentrations is required to meet the NES for $PM_{10}$ (Wilton, 2012).

A testing programme was undertaken to determine the effectiveness of the OekoTube in reducing particulate from coal burning. The tests were carried out in the Applied Research Services (ARS) laboratory in Nelson using two portable samplers located above and below the OekoTube. Tests were carried out over four days with measurements of particulate made each hour for 3-5 hours. The fuels used were sub bituminous coal, wood and sub bituminous coal and bituminous coal. Tests were made for start-up and for low burn and high burn settings.

The current emission factor used for burning coal on a multi fuel burner is around 21 g/kg. Data suggested an average value of around 18 g/kg. However it is noted that the appliance used in the test procedures is modern relative to existing burners in Reefton and a combination of wood and coal were used for some test runs. Based on the information available it is considered that the original value of 21 g/kg is still reasonable for emission inventory and management options assessment purposes.

The OekoTube ESP was most effective in reducing particulate emissions when the fire was operated at low burn setting (90-97% effective) compared with at high burn setting and was around 39% effective during start up. Emissions at high burn, however, were much lower than at low burn meaning the lower efficiency was less significant. The OekoTube was most effective when emissions reductions were important. Thus while the average efficiency across the burn cycles was around 47% the reduction in total emissions across the trialled burn cycle was around 58%.

While there are some limitations in the evaluation, including the absence of data across all aspects of burner operation, results suggest that requiring the installation and maintenance of the OekoTube ESP device on coal and multi fuel burners in Reefton in conjunction with a ban on the use of bituminous coals may be sufficient to achieve the NES for $PM_{10}$. If implementing this as a management option the West Coast Regional Council would need to be satisfied that operation and maintenance procedures are such that the effectiveness of the OekoTube in reducing $PM_{10}$ is permanent.

# 1 INTRODUCTION

The purpose of this report is to evaluate the likely effectiveness of the OekoTube Electrostatic Precipitator (ESP) in reducing $PM_{10}$ concentrations in Reefton.

Concentrations of $PM_{10}$ in Reefton currently exceed National Environmental Standards for Air Quality (NESAQ) (50 µg $m^{-3}$, 24-hour average, one allowable exceedence per year) regularly each winter. In 2012 the NES was exceeded on 27 occasions. Compliance with the NES is required by September 2020 and an interim target of three exceedences must be met by 2016. A 56% reduction in $PM_{10}$ concentrations is required to meet the NES for $PM_{10}$ (Wilton, 2012).

An evaluation of management options for Reefton (Wilton, 2012) suggests the following options may be able to achieve adequate reductions in concentrations in Reefton:

- Prohibit outdoor rubbish burning and the use of open fires, no new installations of multi fuel burners and incentives to encourage 40% of household to replace solid fuel heating methods with cleaner heating options with a 15 year burner phase out, or;
- Prohibit outdoor rubbish burning and the use of open fires and multi fuel burners, or;
- Compulsory use of secondary technology such as ESPs for all coal burners and wood burners not complying with the NES design criteria for wood burners, assuming on going effectiveness of technology can be maintained.

The latter option however, required testing of ESP technology available in New Zealand to confirm that particle reduction efficiencies reported overseas were applicable to the New Zealand situation. This report evaluates the results of testing of the OekoTube ESP device in terms of implications for air quality management in Reefton.

## 1.1 The OekoTube ESP

The OekoTube ESP is an electrostatic precipitator manufactured by OekoSolve of Switzerland to reduce particulate emissions from small scale burning devices up to 40 kW heat output. The OekoTube removes particles using a high voltage electrode which releases electrons into the chimney space containing the particles. The particulates become polarised and move towards the chimney wall and accumulate into coarser material on the chimney wall. It is intended that the resulting particulate matter be removed from the chimney wall by a chimney sweep.

In evaluating their effectiveness it is important to note that electrostatic precipitators such as the OekoTube use an electronic charge to remove particulate emitted from the fire that is in particulate form in the chimney. They do not remove the volatiles that are in gaseous forms when passing the ESP that will condense out to form particulates at lower temperatures. The effectiveness of the OekoTube in reducing $PM_{10}$ from domestic heating will therefore depend on the amount of volatiles in the air stream and the temperature of the flue at the point where the ESP is functioning.

# 2 EMISSIONS FROM COAL BURNERS

The objective of the study was to evaluate the effectiveness of the OekoTube in reducing particles from the coal burner. However, the study also provides information on the mass emissions from coal fired burners in New Zealand. While the sample size was small the data are useful as current emission factors are also based on limited data.

Table 2.1 shows the total burner emissions for each test phase for the pre-OekoTube sampler (prior to removal of particulate). This shows the operation of the burner is significant in terms of $PM_{10}$ emissions with high burn results around 6 g/kg compared with around 28 g/kg for low burn using sub bituminous coal or a mix of sub bituminous coal and wood. Only one test was conducted with bituminous coal but results indicated a high burn emission of around 8 g/kg and a low burn emission around 68 g/kg.

The average emission factors used for coal/ multi fuel burners in the emission inventories and management options assessments is 21 g/kg. The weighted average of the four days from the real life testing based on 19% bituminous and 81% sub bituminous coal is 18 g/kg. It should be noted, however, that the appliance that was used for the testing was a modern multi fuel burner which may be less polluting and not necessarily representative of the Reefton burner fleet.

**Figure 2-1: Summary of test data for particulate emissions prior to exposure to the OekoTube ESP device (B = before)**

| Phase name | Phase | Run 1 (B) | Run 2 (B) | Run 3 (B) | Run 4 (B) |
|---|---|---|---|---|---|
| Start up | 1 | 13 | 11 | 15 | |
| High burn | 2 | 7 | 8 | 4 | 4 |
| High burn | 3 | 5 | 5 | 2 | 8 |
| Low burn | 4 | 25 | 56 | 27 | 68 |
| Low burn | 5 | 9 | 24 | 15 | |
| Average | | 12 | 21 | 13 | 27 |

# 3 OEKOTUBE TESTING

## 3.1 Study design and testing

The study design aimed to provide information on the effectiveness of the Oekotube at various stages of the burn cycle, for a typical sub bituminous coal used in Reefton and using a combination of wood and coal.

The original design was for a three day programme with the following objectives:

Day one – standard burn cycle using sub bituminous coal (Giles Creek)

Day two – standard burn cycle using wood and coal (50:50 mix) (Giles Creek and beech wood 33% wet weight)

Day three – simulated real life operating

The standard burn cycle was:

Phase 1 – start up (one hour)

Phase 2 – high burn (one hour)

Phase 3 – high burn (one hour)

Phase 4 – low burn (one hour)

Phase 5 – low burn (one hour)

Some additional funding was also provided to test the impact of the OekoTube on bituminous coal (day 4). Day four used bituminous coal and measured particulate for phases 2, 3 and 4.

Testing was carried out as detailed in Applied Research Services Limited, (2014). The test method used two portable samplers and accuracy checks were made using the dilution tunnel method specified in the NZS 4013: 1999. A good correlation between the portable samplers and the dilution tunnel was observed ($r^2 = 0.93$). A linear regression plot of the dilution tunnel (y axis) versus the portable sampler gave a slope of 0.94. However, no adjustments were made to the portable sampler values in this analysis owing to the strong influence of one data point on the slope.

The method of determining the effectiveness of the OekoTube was comparison of $PM_{10}$ measured before passing across the OekoTube by using a portable sampler located in the flue prior to ESP exposure to $PM_{10}$ measured after exposure to the OekoTube. In both cases the $PM_{10}$ is extracted from the flue but mass measurements are made after cooling to allow the measurement of condensables. The difference in $PM_{10}$ between the two samplers is assumed to be the effectiveness of the OekoTube.

In addition the Applied Research Services Limited (ARS) report indicates an estimate of effectiveness made by comparing $PM_{10}$ measured using the dilution tunnel (from the top of the flue) to the amount removed by the ESP and retained on the inside of the chimney. The latter particulate is collected by sweeping the inside of the chimney after each phase. Using this method the ARS report indicated that the ESP was removing around 30% of the particulate.

## 3.2 Results

Results from the testing are detailed in the ARS report 14/2660 (Applied Research Services Limited, 2014). A summary is given in Table 3.1 which shows the particulate emissions testing before (B) and after (T) exposure to the OekoTube ESP device. The percentage reduction for each phase and each run is shown in Table 3.2.

The ARS report also identified a strong temperature dependence on the effectiveness of the OekoTube in reducing particulate. Figure 3.1 shows the relationship between flue temperature (top) and the effectiveness of the OekoTube (expressed as ratio of bottom (B) sampler particulate concentrations to top (T) sampler particulate concentrations - a high value indicating more effective operation of the OekoTube). Results illustrate low emissions when flue temperatures are high and limited effectiveness of the Oekotube for flue temperatures more than 120 degrees C at the top of the flue. At temperatures below 70 degrees the OekoTube is typically more effective in removing particulate. The exception is for the one test of bituminous coal under low burn conditions when the temperature was 65 degrees C at the top of the flue and the effectiveness of the OekoTube was low (ratio value of 1.4:1).

**Figure 3-1: Summary of test data for particulate emissions (g/kg) above (T) and below (B) the OekoTube ESP device**

| Phase name | Phase | Run 1 (T) | Run 1 (B) | Run 2 (T) | Run 2 (B) | Run 3 (T) | Run 3 (B) | Run 4 (T) | Run 4 (B) |
|---|---|---|---|---|---|---|---|---|---|
| Start up | 1 | 7 | 13 | 9 | 11 | 6 | 15 | 10 | 4 |
| High burn | 2 | 4 | 7 | 11 | 8 | 4 | 4 | 11 | 8 |
| High burn | 3 | 3 | 5 | 5 | 5 | 2 | 2 | | |
| Low burn | 4 | 1 | 25 | 2 | 56 | 3 | 27 | 48 | 68 |
| Low burn | 5 | 1 | 9 | 1 | 24 | 0 | 15 | | |
| Average | | 3 | 12 | 6 | 21 | 3 | 13 | 23 | 27 |

**Figure 3-2: Percent particle reduction efficiency**

| Phase name | Phase | Run 1 % reduction | Run 2 % reduction | Run 3 % reduction | Run 4 % reduction |
|---|---|---|---|---|---|
| Start up | 1 | 44% | 16% | 57% | -131% |
| High burn | 2 | 44% | -40% | -16% | -26% |
| High burn | 3 | 41% | 0% | 19% | |
| Low burn | 4 | 97% | 97% | 90% | 30% |
| Low burn | 5 | 92% | 95% | 97% | |
| Average | | 64% | 33% | 49% | -25% |
| Average (no negatives) | | 64% | 42% | 53% | 30% |

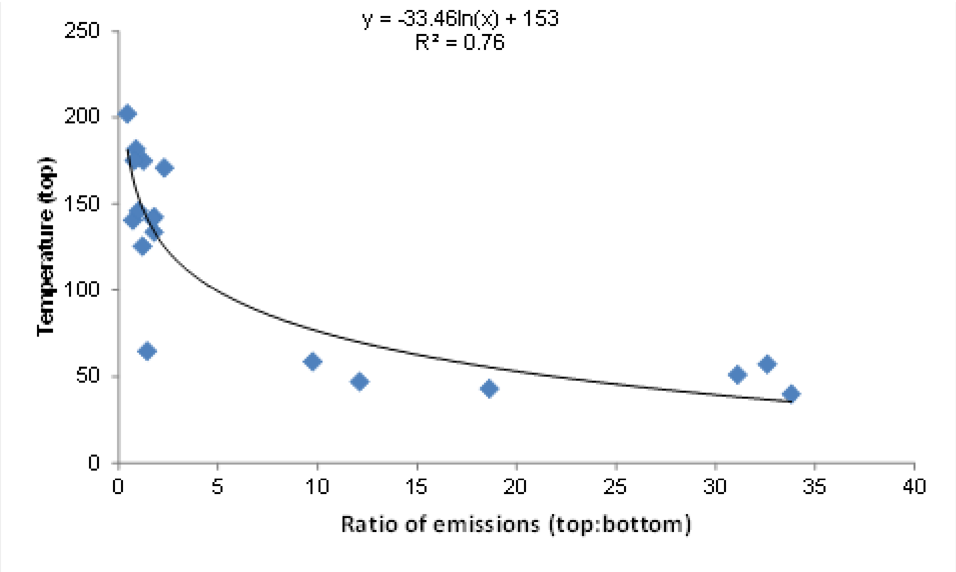


**Figure 3-3: Estimated impact of requiring coal and multi fuel burners install and maintain an operating OekoTube ESP.**

Thus results indicate the effectiveness of the OekoTube is temperature dependent and a much greater efficiency is observed when the appliance is operated on low burn and consequently the flue temperatures are low. This is likely to occur because the lower the flue temperature the greater the proportion of what would be particulate at ambient temperatures is in particulate form in the flue. The ESP device is only effective in removing particles and does not target volatile gases that will condense into particulate. The temperature dependence of the ESP means that additional attention should be given to the burn cycle and how burners are operated in real life.

No information is available on the average burner operating cycle and the proportion of time a burner is operated at low, medium or high. In addition no information is available on the effectiveness of the burner at medium burn. A realistic burn cycle of 12% high burn, 38% medium and 50% low is used for this assessment. Medium burns are assumed to be similar in emissions to the high burn as the temperature data suggests that the flue temperature needs to be less than 70 degrees C for the OekoTube to be highly effective and it would seem likely that medium burn rates would result in temperatures between 70 and 120 degrees. In reality it is also probable that medium burn rates will produce more particulate than high burn rates and the effectiveness of the OekoTube is uncertain. This creates a degree of uncertainty around the analysis.

The average particle reduction efficiency is around 47% when negative data are excluded from the analysis[1]. However, the device is more effective when emissions are highest so a weighted efficiency estimate is required. Based on a 50:50 split between high and low burn outputs and a 19:81 split of bituminous to sub bituminous coal use, the average emission factors are 18 g/kg and 7.5 g/kg for pre OekoTube and post OekoTube respectively. This gives a weighted average efficiency of around 59%.

It is worth noting that this method of evaluating data indicates the OekoTube is much more effective than indicated using the sweeping method from the ARS report (30%). The reason for the difference is unclear although it may be possible that accumulated particulate is falling back into the fire rather than being retained on the chimney walls and consequently is not being measured in the "sweeping".

In addition, the OekoTube appears to be less effective with the bituminous coal (30% compared with 90%+) under the low burn conditions. It is important to note the significant limitations of a single data point for this observation. However, if the OekoTube is less effective with the bituminous coal then a further reduction in $PM_{10}$ emissions would be expected if the use of bituminous coal were also prohibited.

[1] There is no physical mechanism for explaining a negative impact that occurs as a result of the OekoTube. Hence it is assumed that negative values occur for other reasons e.g., condensation of volatiles.

# 4 MANAGEMENT OPTIONS FOR REDUCING $PM_{10}$

The assessment of management options for reducing $PM_{10}$ concentrations in Reefton (Wilton, 2012) includes an evaluation of the impact of prohibiting the use of bituminous coals as well as introducing the requirement for secondary technology such as the OekoTube ESP device for reducing $PM_{10}$ emissions. Both existing assessments rely on assumptions relating to the effectiveness of each option. Reanalysis of the effectiveness of these options based on the test data is required.

## 4.1 Impact of prohibiting the use of bituminous coal

A reduction of around 9% was estimated if bituminous coal was prohibited based on $PM_{10}$ emission estimates of 18 g/kg and 32 g/kg for sub bituminous and bituminous coal respectively. Results from the analysis suggest a slightly greater differential of 15 g/kg to 31 g/kg. The estimated reduction in $PM_{10}$ emissions based on these data is around 12%.

## 4.2 Impact of requiring households to install and maintain an ESP device such as the OekoTube

The use of secondary control measures such as the OekoTube was estimated for Reefton based on the assumption of a 65% efficiency for $PM_{10}$ reduction for wood and coal, and the assumption that the ESP is effective and maintained for the duration of the burners life. This suggested that the device may be effective in reducing $PM_{10}$ concentrations to meet the NES. It is important to note that attention would need to be given to the ongoing maintenance requirements for ESPs to ensure that this assumption is valid. It would not be a set and forget type of regulation if imposed on Reefton as a management measure to reduce $PM_{10}$ concentrations.

Results from this testing indicate that the OekoTube ESP is very effective in reducing $PM_{10}$ concentrations from coal burning at low temperatures when particulate emissions are highest. Limited testing of the effectiveness of the OekoTube on wood burning carried out for Environment Canterbury suggests the OekoTube is less effective for wood burning because of the higher proportion of condensable particulates that are gaseous when passing the ESP. Figure 4.1 shows the estimated impact of requiring an ESP device with the estimated effectiveness of the OekoTube based on a 58% particle reduction efficiency in Reefton. Note this scenario does not include the requirement of an ESP device on wood burners in Reefton.

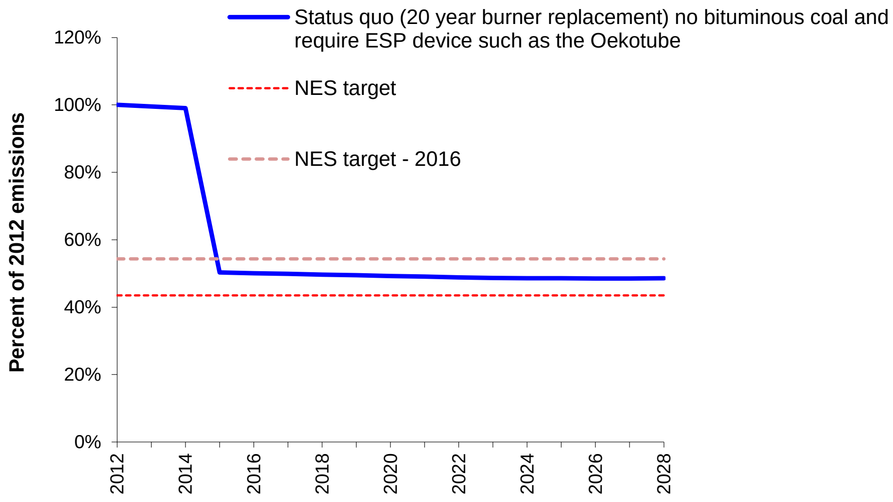


**Figure 4-1: Estimated impact of requiring coal and multi fuel burners install and maintain an operating OekoTube ESP.**

## 4.3 Impact of OekoTube and prohibiting the use of bituminous coal

Test data suggest that $PM_{10}$ emissions from burning of bituminous coal are higher than for sub bituminous coal and that the OekoTube is much less effective in reducing particulate emissions from bituminous coal. The post scrubbing emissions for bituminous coal were still higher at 23 g/kg than for the other fuels (3, 3 and 6 g/kg) and the efficiency under low burn for the one test result was significantly lower at 30% compared with greater than 90%. This suggests additional benefits of prohibiting the use of bituminous coal. Figure 4.3 shows the estimated impact of requiring OekoTubes be fitted to all coal and multi fuel burners in Reefton as well as prohibiting the use of bituminous coal. Note however, the analysis is made in the absence of information on the impact of a medium burn and a relatively small sample size which increases the uncertainty.

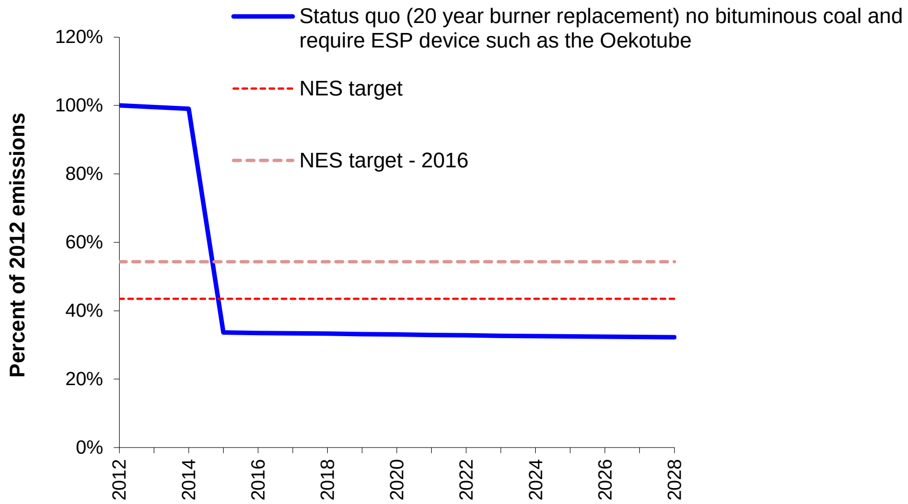


**Figure 4-2: Estimated impact of requiring coal and multi fuel burners install and maintain an operating OekoTube ESP as well as prohibit the use of bituminous coal in Reefton**

## 4.4 Practicalities of implementation

Council would need to be satisfied that the OekoTube can be adequately operated and maintained such that its effectiveness in reducing $PM_{10}$ is perpetual.

It is also important to consider issues of commerciality in writing any rules around the use of ESP devices in Reefton. One option might be to specify a required efficiency that must be demonstrated in a similar situation to the OekoTube testing. In addition it would be of value to specify some design characteristics to ensure overly noisy ESPs or devices that required impracticable maintenance or were easy to tamper with were excluded for example.

# 5 SUMMARY

Concentrations of $PM_{10}$ in Reefton currently exceed National Environmental Standards for Air Quality (NESAQ) (50 µg $m^{-3}$, 24-hour average, one allowable exceedence per year) regularly each winter. A 56% reduction in $PM_{10}$ concentrations is required to meet the NES for $PM_{10}$ (Wilton, 2012). Compliance with the NES is required by September 2020. In addition measures to reduce $PM_{10}$ concentrations to no more than three exceedences of 50 µg/$m^3$ are required to be effective by September 2016.

The OekoTube is an electrostatic precipitator which reduces particulate emissions from the flue of a small scale solid fuel burner. The effectiveness of the Oekotube in reducing particulate from coal burning was tested in the ARS laboratory during January 2014. Tests were carried out over four days with measurements made each hour for 3-5 hours. The fuels used were sub bituminous coal, wood and sub bituminous coal, and bituminous coal. Tests were made for start-up and for low burn and high burn settings.

The average emission factor from the testing was 18 g/kg (weighted average based on 81% sub bituminous coal use) and compares with an average emission factor typically used for coal burning in emission inventories and management options assessments of 21 g/kg. It is considered a reasonable agreement because the testing involved some wood burning (which typically has a lower emission) and because the appliance used was more modern than the majority of coal and multi fuel burners used in Reefton.

Emissions from bituminous coal (one burn cycle only) were about double those from sub bituminous coal.

The OekoTube ESP was most effective in reducing particulate emissions when the fire was operated at low burn setting (90-97% effective) compared with at high burn setting, and was around 39% effective during start up. Emissions at high burn, however, were much lower than at low burn meaning the lower efficiency was less significant. The OekoTube was therefore most effective when emissions reductions were important. Thus while the average efficiency across the burn cycles was around 47% the reduction in total emissions across the trialled burn cycle was around 58%.

A significant observation was that the Oekotube had reduced effectiveness for the one burn cycle when bituminous coal was used.

The impact of regulations including the installation of an OekoTube (or similar) ESP on ambient air quality and compliance with the NES was evaluated. Results suggested that this option, when combined with a 20 year wood burner phase out rule, would probably not be sufficient to meet the NES. However, the inclusion of an additional rule prohibited the burning of bituminous coal is likely to significantly increase the probability of achieving compliance.

If the use of an ESP device such as the OekoTube is included as a regulatory tool for managing $PM_{10}$ concentrations in Reefton then Council would need to be satisfied that the OekoTube can be adequately operated and maintained such that its effectiveness in reducing $PM_{10}$ is perpetual.

# REFERENCES

Applied Research Services Limited. (2014). Testing of the OekoTube Electrostatic Precipitator on Coal Emissions. Applied Research Services Report 14/2660.

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