Technical Paper

Independent Study Shows Sludge Build-up Significantly Affects Hydronic Heating System Performance

The Benefits of Proper Cleaning & Flushing

Introduction

There is considerable evidence that many installers do not correctly flush out hydronic heating systems when upgrading system hardware, controls and/or replacing the boiler. Many boiler replacements are currently directly or indirectly sponsored (or part sponsored) by Government grants and it is thought that inadequate or absence of flushing may be degrading the value of such system improvements. In order to gain a greater understanding of the problems, Sentinel Performance Solutions recently commissioned Gastec-CRE to perform an independent study to determine and quantify:

- any loss in energy efficiency that such inadequate cleaning & treatment may cause, and
- any consequential “gain” (or corresponding absence of loss) of efficiency that can be directly attributable to correct cleaning and treatment.

GaC is a joint venture company uniting the experience and expertise of Gastec N.V., the centre of gas excellence in the Netherlands and CRE Group Ltd the former research arm of the UK's coal industry.

Concept

The study was undertaken on a purpose-built replica of a simple domestic installation consisting of an 11kW/37,500 BTU/hr condensing boiler and five extended surface single panel radiators at two levels. The hydraulic load of the system was accurately balanced with flow and return temperatures set at 149/117°F respectively.

The original concept of the experimental program was to:

- Start with a clean system and determine its thermal efficiency.
- Foul the system with portions of sludge taken from several systems.
- Measure the effect of this upon system thermal performance.
- Fit a new boiler and measure the new efficiency. (This is equivalent to retrofitting a new boiler without power flushing).
- Powerflush the system.
- Measure the system performance with the new boiler in place.
- Add a scale & corrosion inhibitor treatment and study long term performance.

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Measurement of thermal efficiencies

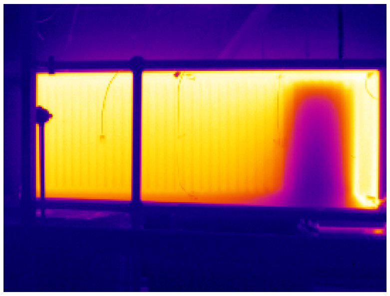
Conventional investigations of domestic boiler efficiencies measure the efficiencies of boilers by the ‘direct’ method; i.e. hot water out, divided by energy in. Larger boilers have traditionally used the ‘losses’ method where the method of efficiency measurement is based on accounting for all heat losses from the boiler (energy in, less the flue and case loss divided by the energy in). This Gastec test program in this study used both approaches, plus a further analysis of radiator area using thermal imaging. The nature of these experiments (i.e. the progressive addition of sludge) was expected to yield results with some manifest experimental error and this was demonstrated in practice. However, by adopting a number of independent but interlocking approaches, Gastec is confident in the validity of the final results.

Initial experiments

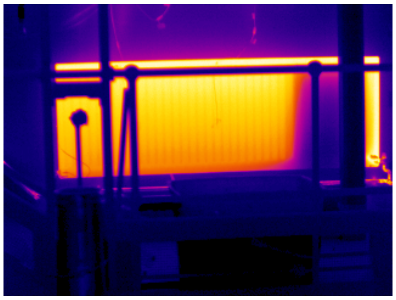
By using a combination of the water flow rate and the difference in flow and return temperatures (ΔT) the system gave an initial heat release from the radiators of 6.15kW/21,000 BTU/hr. This heat rate is considered important as it is considered as equal to the design heat requirement of a typical house when it is 68°F inside the property and 30°F outside.

The efficiency of the boiler was then determined by the direct method as 84%, and by the losses method as 89.8%. This is a surprisingly large difference but probably arises from difficulties in balancing the flow across the 5 radiators.

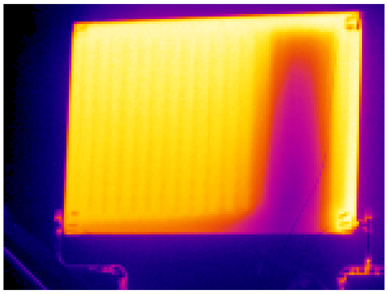
The system was then progressively fouled with portions of sludge to a total of 17.64 lbs (wet) whilst hydraulically re-balancing after every addition. As can be seen from Figure 1 (a) to (e) the radiators suffered significant loss of effective heat transfer area.



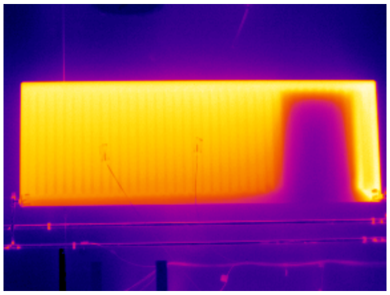
(a) Radiator 1



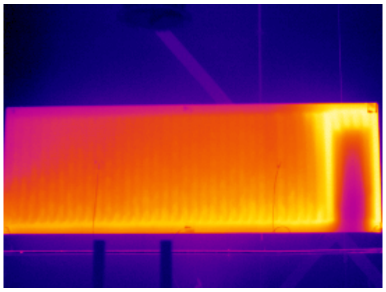
(b) Radiator 2



(c) Radiator 3



(d) Radiator 4



(e) Radiator 5

SENTINEL
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Figure 1

The effect of the addition of the sludge was complex:

- Initially, adding the sludge progressively reduced system flow rate thereby reducing boiler return temperatures. This was associated with a reduction in boiler output which, though temporarily increasing boiler efficiency, more importantly reduced heat to the house, i.e. the system was no longer capable of transferring the required 6.1kW/21,000 BTU/hr to the building.
- This needed to be countered by turning up the pump or opening the valves. This in turn led to an increase in return water temperature leading to a reduction in efficiency. This enabled further sludge to be added up to 14.33 lbs.
- At this point the loss of radiator heat transfer surface was so great that the boiler flow temperature had to be raised. This lowered boiler efficiency still further.
- More significantly, however, this in turn raised return temperatures, causing further loss of efficiency.

After addition of 15.43 lbs of sludge, the system became unstable. In the following Table 1, the flow rate, mean boiler flow/return temperatures and boiler efficiencies are recorded for the period of progressive fouling during which the same overall heat loss from radiators (i.e. house 'comfort' temperature) was maintained. Note the loss in boiler efficiency, the thermal efficiencies by both methods show a fall; in the case of the Losses method by about 2.5%, and by the Direct method in the range 3 to 6% (depending upon the baseline).

Mass sludge lbs	Flow (°F)	Return (°C)	Losses Method* Efficiency (Gross, %)	Delta (%)	Direct Efficiency (Gross, %)	Delta (%)	Flowrate (US Gallons/ min)
0.0	149.00	117.32	89.8		84.0		1.39
1.1	149.00	116.78	89.0	-0.8	87.1	+3.1	1.36
2.2	149.00	119.12	89.0	-0.8	86.5	+2.5	1.46
3.3	149.00	117.86	88.8	-1.0	87.7	+3.7	1.42
4.4	149.00	117.68	89.1	-0.7	87.0	+3.0	1.42
5.5	149.18	119.84	88.9	-0.9	85.3	+1.3	1.47
6.6	149.36	124.52	88.6	-1.2	82.0	-2.0	1.73
7.7	149.36	122.18	89.0	-0.8	82.2	-1.8	1.61
8.8	149.18	121.28	88.7	-1.1	87.3	+3.3	1.60
9.9	149.36	124.34	88.5	-1.3	83.0	-1.0	1.65
11	149.00	122.00	89.1	-0.7	84.2	+0.2	1.62
12.1	149.18	123.44	89.0	-0.8	82.6	-1.4	1.63
13.2	149.36	125.06	88.6	-1.2	82.9	-1.1	1.70
14.3	149.00	125.24	88.8	-1.0	86.6	+2.6	1.78
15.4	160.00	127.22	86.0	-3.8	81.0	-3.0	1.34
16.5	160.00	124.34	87.4	-2.4	83.6	-0.4	1.21
17.6	160.00	124.34	87.5	-2.3	80.8	-3.2	1.09

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Table 1

After this first phase of test work, the boiler was dismounted from the rig and examined. The boiler itself revealed very little in the way of deposits, these being overall an insignificant proportion of the solids added to the system. It was clear that the boiler was NOT heavily fouled and that the problems being experienced with the heating system were due to factors outside the boiler itself.

At the end of the test program, thermal imaging was performed on the radiators (Figure 1(a) to (e)). It can be seen from these images that where sludge had settled, flow had been disrupted resulting in cold areas on radiator surfaces. By measurement of the different colored areas in these Figures it was calculated that the addition of approximately 17.6 lbs of sludge effected an approximately 10 to 15% reduction in active radiator area.

Since we know that heat transfer into the house depends both on the area of active radiator and the flow/return temperatures, it follows that to maintain overall heat transfer, the temperature change across any particular radiator would thus have to be raised by a similar figure i.e. 15%. This can be achieved either by raising return temperatures (i.e. by increased pumping and/or opening the radiator valves) or by raising flow temperatures (which is in turn likely to raise return temperatures). Indeed the measured flow/return and room temperatures, corrected for an initial heat release from the radiators of 6.15kW/21,000 BTU/hr, showed that the overall system change in average temperature range was remarkably similar to the reduction in the active radiator area described above (i.e. approximately 15%).

It can thus be reported with reasonable certainty that the addition of 17.6 lbs of sludge to the 5 radiator system under test reduced its fundamental heat transfer capabilities by approximately 15%.

This increase will be reflected by changes in the boiler performance. The average boiler temperature difference across the gas to water heat exchanger needs to change to accommodate the increase in demand from the heating system and calculations show that this required increase in system temperature (and the effect upon boiler efficiency) is about 3%.

The satisfying aspect of the above results is that all of the three entirely separate techniques would indicate a real degradation in boiler efficiency of approximately 3%.

Second Phase - Changing The Boiler with No Cleaning Agent or Power Flush

In the second phase, the boiler was changed for a new, but identical, model and there was NO flushing of the system. Even re-instating the water flow proved difficult. The system showed virtually no increase in efficiency. The data is shown below (Table 2) together with the conditions at the end of the previous test.

Sludge Added lbs	Flow °F	Return °F	Indirect Efficiency (Gross,%)	Delta %	Measured Efficiency (Gross,%)	Delta %	Flowrate (US Gallons/ min)	Output Heat (BTU/ hr)	Heat Input (BTU/ hr)
0.0	149.00	117.32	89.8		84.0		1.39	21,000	25,374
17.6	160.00	124.34	87.5	-2.3	80.8	-3.2	1.09	21,788	26,980
17.6 (new boiler)	168.98	136.94	86.0	-3.8	77.5	*-6.5*	1.63	25,647	33,127

Table 2

The data confirms that the degradation in boiler performance and heat transfer capability of the system is due to factors outside the boiler itself since even replacement with a new (identical) boiler – often the prescribed remedy for such ills – has no benefit at all. The predominant problem was that, after the new boiler was fitted, the sludge coagulated to such a degree that the boiler and radiator circuit could not transfer the desired quantity of heat from radiators to room.

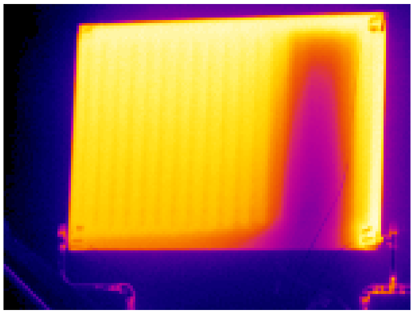
Inspection of the thermal camera images (Figure 1) illustrate the degree of fouling within the radiators. It is clear that the sludge is dramatically affecting both flow and distribution within all of the radiators and this has two distinct effects:

- It reduces heat transfer in the area of the radiator where the deposits occur. This requires the radiator to be operated with the circulating water at a higher temperature than it would need to be in a clean state in order to obtain the desired heat transfer to room.
- It affects the hydraulic balance of the system making it very difficult to keep all the radiators at the desired temperature, without turning the pump setting to ***Maximum.*** This, in turn, can lead to pump noise and excessive velocity in the main flow and return circuit.

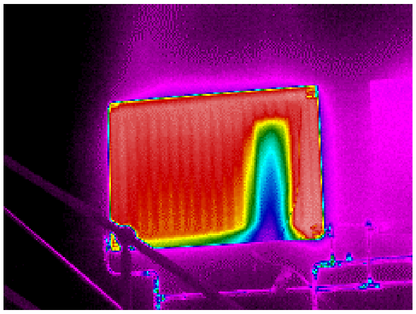
Third Phase - Power Flushing, The Use of Flushing Additives and Mechanical Action

In the third phase, the boiler and system were treated with additives (Sentinel X400) to break down the coagulated sludge and then "power-flushed" to remove the sludge from the system.

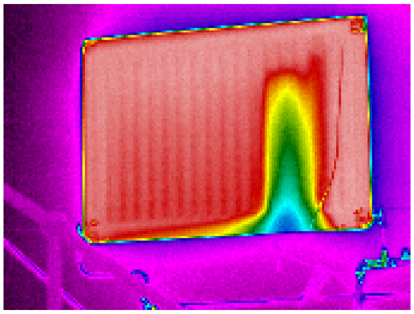
The sequence of events is best described with reference to a series of infra-red thermal image photographs of a single radiator (series of images were obtained of all radiators and were found to be remarkably similar). Those reproduced below of radiator 3 (Figure 2 (a) to (f)) are typical and follow the sequence pre-cleaning, chemical addition, power-flushing and finally flushing plus mechanical vibration.



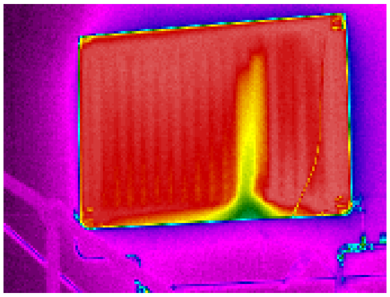
(a) Prior to cleaning



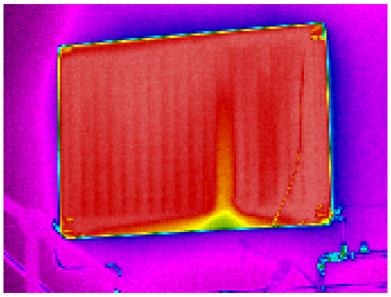
(b) After cold gravity flushing and heating up



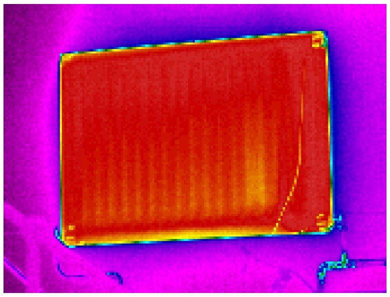
(c) Commencement of hot powerflushing with Sentinel X400



(d) During the hot powerflush



(e) Towards the end of the powerflush – commencement of physical vibration with rubber mallet



(f) End of powerflush cleaning with Sentinel X400

Figure 2

These series of photographs show the significant effect of addition of Sentinel X400 in returning the system to nearly new condition and the extra benefit that vibration can provide.

Fourth Phase - Post Clean, Extended Operation

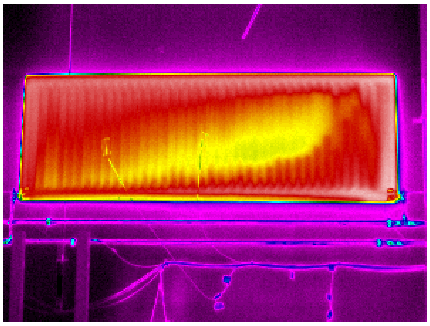


Figure 3

Subsequent to the cleaning studies, Sentinel X100, a long-term corrosion inhibitor, was added to the system. This had no significant impact upon surface temperature. This is entirely as expected as, in the percentage quantities added; this chemical cannot significantly affect the physical properties of the water. Only chemicals that affect viscosity, thermal conductivity and density would be expected to have an effect.

Subsequent to the above cleaning operation, the system was left operational containing the recommended concentration of Sentinel X100. It may be seen from Table 3 that the thermal performance of the system has been restored to approximately the original new condition.

Sludge Added lbs	Flow (°F)	Return (°F)	Indirect Efficiency (Gross,%)	Delta %	Measured Efficiency (Gross,%)	Delta %	Flowrate (US Gallons/ min)	Output Heat (BTU/ hr)	Heat Input (BTU/ hr)
0.0	149.00	117.32	89.8		84.0		1.39	21,000	25,374
17.6	160.00	124.34	87.5	-2.3	80.8	-3.2	1.09	21,788	26,980
17.6 (new boiler)	168.98	136.94	86.0	-3.8	77.5	*-6.5*	1.63	25,647	33,127
Post Clean	142.88	110.48	90.1	+0.3	85.7	*+1.7*	1.42	23,906	29,029

Table 3

Conclusions

Before this study it was thought there were two major factors affecting the performance of a central heating system firstly that of the boiler and secondly of the pipework and radiators.

To consider these in turn: -

- **The boiler.** In the case of a modern boiler with an aluminium heat exchanger, consisting of a single finned coiled tube, the loss of efficiency with age does not come from the “laying down” of corrosion deposits or sludge within the boiler itself. This is because the high velocity within the boiler is generally sufficient to effectively “scour” such deposits. However, some loss of efficiency can occur in hard water areas due the tightly adhering scale deposits that form on the heat exchanger metal surface. These scales are thermally insulating and derive from the hardness salts in the supply water. In poorly designed open vented systems where evaporative losses may be continually replenished with fresh water, scale accumulation and loss of efficiency can become severe.

- **The pipework and radiators.** The corrosion deposits within an elderly hydronic heating system can cause a substantial reduction in the effectiveness of the radiators themselves or the system as a whole by about 15%. Effects can be as simple as a mechanical blockage adjacent to the water entry point or the blockage of valves.

Either of these two phenomena is certainly sufficient to cause substantial hydraulic imbalance leading to excessive flow through some radiators (with corresponding overheating) and cold spots in others. The only technique the householder has for overcoming this effect is actually turning up the room thermostat, so increasing the delivery of heat to water in the hydronic heating circuit.

When explained in this fashion, it is clear that these are exactly the problems that manifest themselves in so many old heating systems. This is especially true with systems fitted with (or retrofitted with) thermostatic radiator valves that have relatively small orifices.

Raising water temperatures (and possibly reducing water flows) also increases the likelihood of oxidation of the *outside* of the heat exchanger within the boiler thereby reducing external heat transfer coefficients and reducing boiler efficiency. This can lead to premature failure of fans etc.

The nature of the restriction formed within radiators is well illustrated within the photographs within this paper. These deposits both “blind” the internal surface of the radiator and distort the water flow causing radiators to display unusually high pressure drops. This phenomenon will eventually lead to the water flows through the system becoming unbalanced.

- This absence of hydraulic balance can lead to wasteful overheating and under-heating of rooms unless each radiator is fitted with a thermostatic valve. Certainly, a system controlled by a single room thermostat is unlikely to give customer satisfaction, will waste energy, increase fuel bills and increase carbon dioxide emissions.

- As can be seen from the efficiency figures, the requirement to raise water temperature in the hydronic heating circuit has a significant effect upon boiler efficiency, especially with modern condensing boilers.

When a hydronic heating system has a major overhaul, as will occur when fitting a new boiler it is considered essential to return the system to as nearly new condition as possible. However the work has shown that replacing the boiler with a new clean unit has no significant benefit IF the system has not been power-flushed and treated. This “loss” of efficiency is almost equivalent to a full standard efficiency energy band, and, more seriously, is likely to leave an unhappy customer who still does not have a correctly balanced heating system giving uniform heat in all rooms. Thus the whole system should be effectively cleaned at the same time as the boiler change. There are a variety of ways of carrying out this cleaning but, as shown in this study, the best approach is full powerflushing with an appropriate chemical cleaner such as Sentinel X400.
To be more specific:

- The addition of a dispersant such as Sentinel X400 demonstrably aids the removal of sludge as part of the power flushing process.

- The power flushing process cannot be a remote process carried out from the boiler. The preferred approach is to subject individual radiators to reasonably prolonged vibration either by means of air entry or a rubber mallet. This is inevitably a time consuming process requiring attention to detail but is essential if the system is to be returned to anything like an as new condition.

- The system can be successfully restored using a combination of Sentinel X400 and use of the powerflush technique.

The question could be asked if, on a perfectly designed system with boiler operation primarily controlled by room thermostat rather than boiler thermostat, a cleaned system operates more efficiently. The answer is yes: the cleaner radiators will allow for lower average operating temperature (irrespective of means of control i.e. valve or room thermostat) and thus will promote lower average water temperature yielding increased boiler efficiency.

Recommendations

Periodically, as part of routine hydronic heating system maintenance, during **all** boiler changes and where there is any indication of system corrosion, systems should be thoroughly cleansed. This is most conveniently performed by means of a powerflush of the whole system and should be performed by an appropriately trained operative, using a chemical additive to assist the break-up of sludge deposits. The process should preferably include inducing mechanical vibration in individual radiators.

The expected result is;

- An increase in the fundamental heat transfer capabilities of the system radiators by up to 15%, providing greater uniformity of radiator temperature (and thus greater client satisfaction).
- An increase in overall boiler energy efficiency of up to 3%.
- Less risk of system hydraulic imbalance (and so greater client satisfaction).
- Lower fuel bills and less carbon dioxide emissions.

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