Research Paper

# The use of a flushing and cleaning protocol to remove foreign contaminants – a study from a newly built heat transfer plant with a capacity of 100 metric tonnes

CrossMark

Christopher Ian Wright *

*Research and Development, Global Group of Companies, Cold Meece Estate, Cold Meece, Staffordshire ST15 0SP, UK*

HIGHLIGHTS

- Cleanliness is critical to the effectiveness and safety of a heat transfer system.
- Flushing and cleaning fluids are recommended during the building of new systems.
- The current research assesses the effectiveness of flushing and cleaning protocols.
- Data highlight the value of monitoring water during a new system build.
- It is concluded that the presence of water may be an early sign of contamination.

ARTICLE INFO

ABSTRACT

Heat transfer fluid (HTF) cleanliness is critical to the effectiveness and safety of an HTF system. Routine monitoring of HTF condition is a critical part of ongoing HTF system maintenance. However, the condition of any fluid introduced into a HTF system needs to be monitored closely to ensure that foreign contaminants are not introduced. Such contaminants act to accelerate the ageing of an HTF once in operation. The current research concerns the flushing and cleaning protocol that is used to remove foreign contaminants during the building of a new HTF system. The current study was performed in Scandinavia for a client building a new HTF system that had a capacity of 100 metric tons. The system was flushed with Globaltherm® C1 was used to flush and clean the system prior to filling with a synthetic HTF. The value of the protocol was assessed in terms of its ability to remove contaminants – water, environmental and system build contaminants. The protocol involved the use of a fine filter (15 microns pores) and laboratory analysis to assess cleanliness of the fluid. The results from nineteen fluid samples are presented herein. Results show the presence of water and particle contaminants (4, 6 and 14 microns in size) including silicon, aluminium, iron, calcium and zinc. The flushing and cleaning fluid works by suspending particles in solution and these are subsequently drained from the HTF system. The detection of particles in the fluid demonstrates that the flushing and cleaning fluid and the protocol are effective in removing finer particles from a system. Further analysis assessed the relationship between water and particle contaminants. Results showed a positive association between water and the presence of larger particles (i.e., 14 microns). No association was found between water and smaller particles (4 and 6 microns). These data highlight the value of monitoring both water and particle contamination, and that water may be a substitute method to measuring particles directly. The presence of water in a fluid can be observed and detected onsite, so this may be an early sign of other contaminants present in a newly build HTF system. To conclude, the flushing and cleaning protocol described herein is effective in the removal of contaminants during a HTF system build. This protocol has been shown to be effective by subsequent laboratory analysis. The presence of water may be an early sign of environmental contamination and the formation of rust.

© 2016 Elsevier Ltd. All rights reserved.

---

## 1. Introduction

The global heat transfer fluid (HTF) market is projected to be worth around two and half million dollars by 2017, which is one and a half times its value in 2011 [1]. HTFs are used in a wide range

of industrial processes that use indirect heat to process foods and chemicals, and to derive electricity from concentrated solar power plants [2]. The cost and production efficiency of such plants is paramount [3] with interruptions or inefficient production leading to a reduction in overall output relative to increased production costs. Therefore, increasing or sustaining output relative to production cost is critical for the viability of an HTF plant. The maintenance of an HTF plant is central to maintaining plant operation and also ensuring the longevity and safety of the overall plant [4].

In every day practise, the condition of an HTF is assessed routinely and is an indirect measure of the condition and safety of the plant itself [5]. Indeed, routine samples drawn from a system can be subsequently analysed to assess the oxidative state, thermal degradation and contamination from foreign particles including water and wear particles [6]. This testing is conducted in a laboratory and use international test methods including those defined by the American Society for Testing and Materials (ASTM) [7]. Test results are then compared against the safety data sheet to determine if a particular parameter is in or out of specification and what intervention, if any, is needed [5].

However, testing is conducted after a fluid, for example an HTF or flushing or cleaning fluid, has been sampled and there is a lag between the time a fluid has been sampled and the time when the test results are available. The only way to reduce the lag between sampling and the time to results is to have a laboratory onsite where the fluid is sampled, although this will only marginally reduce the timeframe. The other way is to have technology, e.g., the Global Thermocare Sensor [8] that enables sampling and analysis to be done in real-time when on-site. Either way the testing is used to confirm the effectiveness of an intervention on the physical condition of a fluid or HTF [8]. The current case presents the data from a new HTF system build. Such systems are at potential risk from foreign contaminants as they are exposed to the environment whilst being built and there is an opportunity for contaminants such as water, soil and welding slag to ingress [9]. These need to be removed prior to filling with a virgin HTF as such contaminants accelerate the ageing [10] of an HTF and have a negative effect on the production-to-cost ratio. In this study case, a flushing and cleaning protocol was used to clear contaminants from the HTF system and data are presented to show that this approach is effective as shown by the extent of contaminants removed from the HTF system.

Hence, the objective of this work was to demonstrate the effectiveness of using a flushing and cleaning protocol prior to filling a newly built system with a virgin HTF. Moreover, the secondary aim was to explore the association between contaminants to see if the monitoring of water contamination is a global indication of HTF system contamination.

## 2. Experimental methods

### 2.1. Background

The current study was performed in Scandinavia for a client building a new HTF system with a capacity of 100 metric tons. The customer commissioned the flushing and cleaning of the system with Globaltherm® C1 [11]. The system was then subsequently filled with a virgin heat transfer fluid.

### 2.2. Flushing and cleaning a heat transfer fluid system

It is best practice to flush a newly built system prior to filling with a virgin heat transfer fluid. The reason being two-fold – heat transfer fluids are an expensive capital investment and if contaminated with foreign bodies, these can catalyse the thermal degradation of a virgin heat transfer fluid and shortening of the life of the fluid [10].

### 2.3. The flushing and cleaning process

Globaltherm® C1 was used to flush and clean the system. The purpose of flushing and cleaning is to suspend contaminants in the fluid so they can be removed through filtration and drainage of the fluid from the system. The flushing and cleaning methodology has been described previously [12] and described briefly herein.

Firstly, the low, high and dump lines of the HTF system header tank need to be identified. They are then checked to make sure they are not blocked and that the flushing and cleaning fluid is flowing. The flushing procedure is initiated by attaching a suction pump and hose to the dump valve on the HTF system header tank, which allows the flushing and cleaning fluid to be drained from the HTF system and for air to also be removed. The valve from the header tank is closed and the flushing and cleaning fluid is pumped into the system, from the lowest level of the system, and passes through the heater coils, the production line and to the header tank. Filling is stopped once a pre-defined fill level has been reached. The system is vented to atmosphere to stop air from being circulated around HTF system.

### 2.4. Taking a representative sample of the flushing and cleaning fluid

Prior to flushing the HTF system, the flushing and cleaning fluid was held in ISO storage tanks. From here the fluid was pumped into the HTF system until it was filled (125% of the system's volume). A stable circulation was then established.

Whilst in circulation the flushing and cleaning fluid was filtered using a mobile filtering unit with a pore size of 15 microns. This means that the size of the contaminating particles concerns only those less than 15 microns in diameter.

A 500 ml sample of the fluid was taken using a custom designed closed sampling device [5]. Nineteen samples were taken in total.

### 2.5. What analysis was conducted on the sampled flushing and cleaning fluid?

Samples were then sent for chemical analysis, which is conducted according to ISO14001 [13] and ISO17025 [14]. Water content, fluid cleanliness and contaminants contained in the fluid were conducted.

Chemical analysis was used to assess the water content in the fluid and conducted according to ASTM D6304. A new fluid has a typical water content less than 100 parts per million.

The fluid's cleanliness was assessed according to ISO cleanliness standard ISO 4406:1999) [15]. Particle size is quantified into three sizes: 4, 6 and 14 μm per ml (see Table 1) and expressed using this formula: XX/YY/ZZ to reflect the relative distribution of the three particle sizes in the sample. The fluid cleanliness for a new fluid needs to be defined with the customer, but is generally around 16/14/11 [12].

Insoluble materials (silicon, aluminium, iron, calcium and zinc) in the flushing and cleaning fluid were measured and graded on a scale from 1 (not present) to 4 (a major constitute).

### 2.6. Data analysis

Analysis focused on three aspects. The first was to assess the existence of a linear relation between water content and fluid cleanliness of the flushing and cleaning fluid. An x–y plot was used to visually inspect this relationship. A Pearson correlation (r-value) was calculated for the 19 paired samples and a P-value calculated to assess if the relationship reached statistical significance.

The second analysis focused on the comparison of values within groups. In this case particle size scores were compared using a single

**Table 1**
The classification of particle sizes [8].

| Particle size score | Particles per ml | |
|---|---|---|
| | Greater than | Equal or less than |
| 24 | 80,000 | 160,000 |
| 23 | 40,000 | 80,000 |
| 22 | 20,000 | 40,000 |
| 21 | 10,000 | 20,000 |
| 20 | 5000 | 10,000 |
| 19 | 25,000 | 50,000 |
| 18 | 13,000 | 26,000 |
| 17 | 640 | 1280 |
| 16 | 320 | 640 |
| 15 | 160 | 320 |
| 14 | 80 | 160 |
| 13 | 40 | 80 |
| 12 | 20 | 40 |
| 11 | 10 | 20 |
| 10 | 5 | 10 |
| 9 | 2.5 | 5 |
| 8 | 1.3 | 2.6 |
| 7 | 0.64 | 1.28 |
| 6 | 0.32 | 0.64 |

factor ANOVA. These within group comparisons were conducted for both low and high water content groups.

The third analysis made comparisons between low and high water content groups for both mean particle scores and insoluble materials. Differences between variables were assessed using a two-tailed unpaired t-test assuming equal variance.

### 2.7. Data presentation

Data are presented as mean ± SD otherwise stated. All statistical analyses were conducted using Microsoft Excel 2007. A P-value <0.05 was taken as demonstrating a statistically significant effect.

## 3. Results

Data are from 19 samples with mean water content being $113 \pm 209$ ppm and mean particle size scores as follows: 4 microns, $22 \pm 1$; 6 microns, $20 \pm 2$; and 14 microns, $16 \pm 3$ (please see Table 2).

### 3.1. The relationship between water content and fluid cleanliness scores

Water was correlated with particle sizes (see Table 3). Water content did not relate with any of the reported particle sizes ($P > 0.05$).

### 3.2. The relationship between different fluid cleanliness scores

Comparisons between particles sizes revealed strong positive relationships ($r > +0.7$; $P \leq 0.0001$) between 6 microns and both 4 and 14 micron groups. A moderate ($r = +0.441$) relationship between 4

**Table 2**
Mean water content and distribution of particles sizes for all samples of the flushing and cleaning fluid.

| Parameter | Water, ppm | Particle size score, particle size per ml | | |
|---|---|---|---|---|
| | | 4 microns | 6 microns | 14 microns |
| Mean ± SD (range) | 113 ± 209 (1 to 936) | 22 ± 1 (10 to 23) | 20 ± 2 (17 to 22) | 16 ± 3 (11 to 21) |

Note: ppm, parts per million; SD, standard deviation. Baseline values, recorded prior to cleaning and flushing were: water, 28 ppm; and 20/17/16 (4/6/14 microns).

**Table 3**
Linear relationship between water content and particle sizes (4, 6 and 14 microns) for all 19 samples.

| Parameter | Pearson correlation coefficient | | |
|---|---|---|---|
| | 4 microns | 6 microns | 14 microns |
| Water (all samples) | r = −0.12 (P = 0.611) | r = +0.10 (P = 0.686) | r = +0.35 (P = 0.142) |
| 4 microns | r = +1.00 (P < 0.0001) | r = +0.81 (P < 0.0001) | r = +0.44 (P = 0.059) |
| 6 microns | r = +0.81 (P < 0.0001) | r = +1.00 (P < 0.0001) | r = +0.77 (P = 0.0001) |
| 14 microns | r = +0.44 (P = 0.059) | r = +0.77 (P = 0.0001) | r = +1.00 (P < 0.0001) |

The relationship between parameters was assessed using a Pearson correlation coefficient (r-value) and significance depicted with a P-value, presented in parenthesis.

and 14 microns groups, which was not significant ($P = 0.059$) (Table 3).

### 3.3. The association between water content and fluid cleanliness

#### 3.3.1. Low water content group only
Table 4 presents results based on water content (<100 and ≥100 ppm). For less than 100 ppm there was a significant difference between particle size groups (ANOVA) with the lowest particle size (4 microns) having the highest particle count and the highest particle size (14 microns) having the lowest particle count (Table 4). Comparisons between these groups revealed statistical differences ($P < 0.05$, unpaired t-test) between all particle size groups for this group.

#### 3.3.2. High water content group only
The same comparisons were conducted as for the low water content group and no significant differences ($P > 0.05$) were found and this suggests that particle counts between groups was similar (Table 4).

#### 3.3.3. Comparison between low and high water content groups for a given particle size
By dividing the groups based on water content it is possible to compare the same particle size groups (Table 4 and Fig. 1). Comparison of the 14 micron groups revealed a statistically significant difference between the two groups ($P = 0.0004$, unpaired t-test). However, no differences ($P > 0.05$) were found when 4 and 6 micron groups were compared.
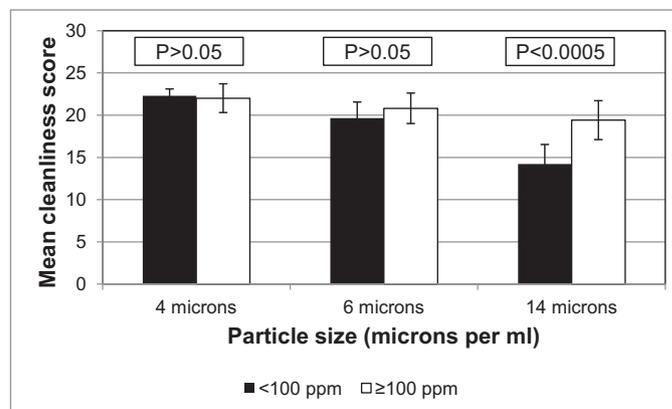


**Fig. 1.** Mean particle size grouped by low (<100; filled bars) and high (≥100 ppm; open bars) water content.

**Table 4**
Mean particle size scores based on low (<100 pm) and high (≥100 ppm) water content.

| Water content, ppm | Particle size score | | | P-value |
| --- | --- | --- | --- | --- |
| | 4 microns (A) | 6 microns (B) | 14 microns (C) | |
| <100 (mean ± SD, 42.1±31.6), n = 14 | 22.3 ± 0.8 | 19.6 ± 1.9 | 14.2 ± 2.3 | *P < 0.0001, (A) vs. (B) vs. (C) <br> **P < 0.0001: (A) vs. (B); (B) vs. (C); (A) vs. (C) |
| ≥100 (mean ± SD, 313.0 ± 355.0), n = 5 | 22.0 ± 1.7 | 20.8 ± 1.8 | 19.4 ± 2.3 | *P > 0.05, (A) vs. (B) vs. (C) <br> **P > 0.05, (A) vs. (B); P > 0.05, (B) vs. (C); P > 0.05, (A) vs. (C) |
| *P-value (<100 vs. ≥ 100 ppm) | P = 0.627 | P = 0.253 | P = 0.0004 | NA |

Data are presented as mean ± SD from 19 samples. NA, not applicable. Statistical test: *, single factor ANOVA; and **, unpaired t-test assuming equal variance. Typically Globaltherm® C1 has a water content <100 ppm and this is defined as normal and thus within normal specification.

### 3.4. Analysis of insoluble materials in the flushing and cleaning fluid

Table 5 shows the insoluble material identified in the flushing and cleaning fluid. The highest contaminant level was for silicon but it did not differ (P > 0.05, unpaired t-test) by water content. This was also true for aluminium, calcium and zinc (P > 0.05, unpaired t-test). The only exception was iron, which was significantly greater (P = 0.004, unpaired t-test) in the high water content group (Table 5).

## 4. Discussion

The current study is the first to assess the relationship between the foreign contaminants usually encountered during the initial building of an HTF system. Results demonstrated an association, but not a linear correlation, between water content and fluid cleanliness. Data showed that raised water content was associated with a corresponding rise in the largest particles (i.e., 14 microns). This rise may be due, in part, to elevations in the iron content (+30.8% in the high water content group compared with the low water content group) as this was also associated with an elevation in water content. The current findings also demonstrate that the protocol employed for the flushing and cleaning of the current newly built HTF system was effective in the removal of contaminants.

The cleanliness of a fluid (i.e., fewer impurities) is critical to its long-term health. This is especially true for HTFs that routinely operate at high temperatures and the presence of impurities works to accelerate their degradation, which ultimately shortens their life and potentially interrupts system operation [10]. Reducing the contaminants in a system and increasing their removal from a system is therefore important to the longer-term functionality of the HTF

and the HTF system. This paper explored the relationship between the common contaminants of a newly built HTF plant. Indeed, if left, new plants will be exposed to contaminants from dirt and soil, from moisture in the atmosphere and the by-products of construction such as welding slag. The current case was conducted during the flushing and cleaning protocol normally employed by Global Heat Transfer. The methodology for flushing and cleaning has been reported previously [12] and is designed to physically flush and clean a newly built or existing HTF system before it is filled with a virgin HTF. The flushing and cleaning fluid is a physical intervention used to mechanically remove contaminants from the HTF system. This is combined with filtration of the fluid using a filter with a 15 micron pore [12]. This protocol is important for the following reasons:

1. It demonstrates that the flushing and cleaning protocol was effective and when onsite engineers need to follow the same protocol to achieve the same results.
2. Ensuring the subsequent virgin HTF is not contaminated. Indeed, the overall aim of flushing and cleaning is to remove contaminants but, more importantly, ensure that the physical properties of a fluid are almost identical to a virgin HTF (the physical properties routinely sampled are shown in Table 6). This is beyond the scope of the current study, but this has been shown in past reports [12].
3. The results of onsite sampling are delayed until the samples can be analysed in the laboratory. This is quite normal as a sample will need to be shipped to a laboratory for subsequent analysis. Hence, the results will not always be immediately available. Following a protocol ensures that this is not an issue provided the engineering team commissioned to do the work and trained on the process and procedure. Obviously on site analysis can be used such as condition monitoring probes to monitor water contamination in samples [6].
4. A set protocol also ensures that there is an audit trail of test results. This is also very important for both the client and the company commissioned to perform the work. Indeed, the client wants reassurance that the HTF system has been flushed and cleaned and that the virgin HTF has not been contaminated during the process. Hence, they want reassurance that the process is effective. In contrast, the company performing the work want to demonstrate that the flushing and cleaning fluid was not con-

**Table 5**
Insoluble materials identified in the fluid and grouped according to low (<100) and high (≥100 ppm) water content.

| Data presentation | | Water content, ppm | | P-value |
| --- | --- | --- | --- | --- |
| | | <100, n = 14 | ≥100, n = 5 | |
| Silicon | Mean ± SD | 4.00 ± 0.00 | 4.00 ± 0.00 | P > 0.05 |
| | Range | 4.00 to 4.00 | 4.00 to 4.00 | NA |
| | Mode | 4.00 | 3.00 | NA |
| Aluminium | Mean ± SD | 2.21 ± 0.43 | 2.20 ± 0.45 | P > 0.05 |
| | Range | 2.00 to 3.00 | 2.00 to 3.00 | NA |
| | Mode | 2.00 | 2.00 | NA |
| Iron | Mean ± SD | 2.14 ± 0.36 | 2.80 ± 0.45 | P = 0.004 |
| | Range | 2.00 to 3.00 | 2.00 to 3.00 | NA |
| | Mode | 2.00 | 3.00 | NA |
| Calcium | Mean ± SD | 2.00 ± 0.00 | 2.00 ± 0.00 | P > 0.05 |
| | Range | 2.00 to 2.00 | 2.00 to 2.00 | NA |
| | Mode | 2.00 | 2.00 | NA |
| Zinc | Mean ± SD | 1.07 ± 0.27 | 1.20 ± 0.45 | P > 0.05 |
| | Range | 1.00 to 2.00 | 1.00 to 2.00 | NA |
| | Mode | 1.00 | 1.00 | NA |

Data are presented from 19 samples. Individual samples were graded from 4 to 1; 4, a major constitute; 3, a minor constitute; 2, a trace constitute; and 1, not being present constitute. Means were compared using an unpaired t-test assuming equal variance. NA, not applicable; ppm, parts per million; n, number of samples.

**Table 6**
Typical parameters tested and standard test methods used.

| Parameter | Test method |
| --- | --- |
| Carbon residue, % weight | IP14 |
| Strong and total acid numbers, mg KOH/g HTF | IP139 |
| Closed and open cup flash point temperatures, °C | ASTM93 and ASTM92 |
| Fire point temperature, °C | ASTM92 |
| Viscosity, mm$^2$/s (at 40 °C) | IP71 |
| Water content, ppm | ASTM D6304 |
| Wear debris (insolubles) | PQ Analex Method |
| Elements, ppm less than 5 μm (solubles) | ASTM D5185 |

taminated when it arrived on site and it did not lead to the contamination of the HTF system. Also, assuming they have been commissioned to fill the HTF system, they need to demonstrate that the virgin HTF is not contaminated and within the specifications defined in the safety data sheet. Hence, the company is keeping a trail of the quality and condition of the fluids at each step in the process.

Past research investigated the value of flushing and filtering of an HTF during the building of new systems [12]. The data presented showed that water content and iron increased significantly between storage and filling of the HTF system. A further observation was that the particle counts inversely related to particle size. The current research is therefore exploratory research building on previously presented mean data to assess the potential relationship between contaminants and contaminants and water during an HTF system build.

Data showed strong positive linear relationships between particle counts (specifically 4 and 6 microns and between 6 and 14 microns; Table 4). Particle counts were then correlated with water and this revealed no significant relationships. Suggesting that water is not a predictor of particle contamination during the flushing and cleaning of a newly built HTF system. However, using a threshold value of 100 ppm of water, which is critical as 'within normal limits' is defined as being less than 100 ppm, did unveil an association between water contamination and the largest particle count. This suggests that the largest particles that are able to pass through the filter increase as water increases. This was shown by comparing low and high water content groups at the same particle size counts (see Table 4).

The last aspect was to define what particles were actually in the fluid. Table 5 shows the insoluble materials detected in the fluid samples and demonstrates that there were no differences in the mean levels of silicon, aluminium, calcium and zinc. There was a difference in the level of iron, however, with the mean value being higher in the high water content group. The explanation for this only became apparent when inspecting the filters and speaking to the engineers onsite. A fine brown coloured material (see Fig. 2) was found and the engineers confirmed that the system components had been left exposed and a fine brown covering had been detected, indicated that the system had a small amount of rusting. This would seem to be the logical explanation for the association between the level of iron and water content.

So what are the practical implications of these findings? The first point to make is that these findings clearly show the need to monitor more than one parameter during flushing and cleaning. Simply monitoring water is not sufficient as it does not reflect the presence of all particles in the fluid. With that said, however, it does seem fair to say that if water is detected in a fluid during flushing and cleaning of the HTF system, then there is a good chance that it also contains other contaminants.

Another practical implication of this research is the need for subsequent follow-up after the virgin HTF has been added to the system. This is used to monitor contamination and the opportunity to aggressively maintain contamination levels within pre-defined limits (usually defined with the client). This needs to be combined with a routine sampling and chemical analysis programme, which is needed to assess the physical properties (see Table 6) of the HTF and enables the condition of the HTF to be monitored. This is important as any changes in the condition of the HTF can be detected and this gives the client time to plan any interventions that are needed.

### 4.1. Limitations

The current study can be criticised as the research dealt with only flushing and cleaning fluid samples. Hence, questioning how



**Fig. 2.** Images of the system filters.

relevant is it to all fluids. This should not be interpreted as a limitation, however, as the principles presented are relevant to any fluid that is used to physically flush a HTF system. Indeed, use a proven and effective protocol and combine it with testing to assess the extent of contamination during the building of new HTF systems. Then use routine sampling and chemical analysis to monitor the condition of the virgin HTF. A further limitation is the small sample size – 19 samples from 1 system. The current analysis revealed a number of statistically relevant findings, but the results from other sites would confirm the current findings and should be considered in future publications.

### 5. Conclusions

The flushing and cleaning protocol, which is conducted prior to filling with a virgin HTF, was shown to be effective in the removal of water and environmental contaminants. This is relevant to current practice because there is a delay between the actual sampling and subsequent chemical analysis of a fluid, as the sample needs to be sent to the laboratory for further analysis. So when onsite engineers need to be confident that the protocol being used is effective at flushing and cleaning an HTF system. Especially if the HTF system is being conducted before laboratory results are available.

The current research demonstrated no linear relationship between the water and particulate counts, although there was a clear

relationship between water levels and particle counts that measure 14 micron. With high water contamination, particles were high and vice versa. This was not true for smaller particle counts of 4 and 6 microns. This is relevant because it demonstrates that water contamination is associated with larger particle contamination. Moreover, subsequent analysis using Bland–Altman plots suggests that measuring or detecting the presence of water is a good indicator for the presence of environmental contamination following a new system build. Measuring water may also be a good method that can be used on site to highlight the presence of environmental contamination.

Lastly, this research emphasises that flushing and cleaning combined with a filter is effective in the removal of environmental contaminants and this is important to the client as it works to safeguard the long-term health of the virgin HTF subsequently added to the HTF system.

## Acknowledgements

## References

[1] ReportsnReports.com updates its store with "Global Heat Transfer Fluid Market [Thermic Fluid/High Temperature/Synthetic Heat Transfer Fluids] By Product Type [Mineral Oils, Silicone & Aromatics, PAG & Glycol Based Products & Others], Applications & Geography – Forecasts To 2017" market research report. <http://www.marketsandmarkets.com> (accessed 22.10.14).
[2] K. Vignarooban, X. Xu, A. Arvay, et al., Heat transfer fluids for concentrating solar power systems – a review, Appl. Energy 146 (2015) 383–396.
[3] Y. Tiana, C.Y. Zhaob, A review of solar collectors and thermal energy storage in solar thermal applications, Appl. Energy 104 (2013) 538–553.
[4] A.G. Fernandez, M. Cortes, E. Fuentealba, et al., Corrosion properties of a ternary nitrate/nitrite molten salt in concentrated solar technology, Renew. Energy 80 (2015) 177–183.
[5] C.I. Wright, Thermal heat transfer fluid problems following a system flush with caustic and water, Case Stud. Therm. Eng. 2 (2014) 91–94.
[6] C.I. Wright, T. Bembridge, Reliably measuring the condition of mineral-based transfer fluids using a permittivity sensor – practical application to thermal fluid heat transfer, Case Stud. Therm. Eng. 6 (2015) 162–170.
[7] American society for testing and materials. <http://www.astm.org> (accessed 14.09.14).
[8] C.I. Wright, Effective management of heat transfer fluid flash point temperatures using a light-ends removal kit (LERK), Case Stud. Therm. Eng. 4 (2014) 9–14.
[9] T. Ennis, Safety in design of thermal fluid heat transfer systems. Symposium series number 155, Hazards XXI (2009) 162–169.
[10] O.W. Wagner, Chapter 2: heat transfer technique with organic media, in: Heat Transfer Media, second ed., Maria-Eich-Straße, Graefelfing, Germany, 1997, pp. 4–58.
[11] Globaltherm® C1. <http://Globalheattransfer.co.uk>, (accessed 17.02.15).
[12] C.I. Wright, E. Picot, A case study to demonstrate the value of a system flush and clean prior to filling a plant with virgin heat transfer fluid, Heat Transfer Eng. (2015) doi:10.1080/01457632.2015.1067061.
[13] ISO 14001:2004. Environmental management. <http://www.iso.org/iso/iso14000> (accessed 22.10.14).
[14] ISO/IEC 17025:2005. General requirements for the competence of testing and calibration laboratories. <http://www.astm.org/Standards/ANSISO17025.htm> (accessed 22.10.14).
[15] ISO 4406:1999. Method for coding the level of contamination by solid particles. <https://www.iso.org/obp/ui/#iso:std:iso:4406:ed-2:v1:en> (accessed 17.02.15).