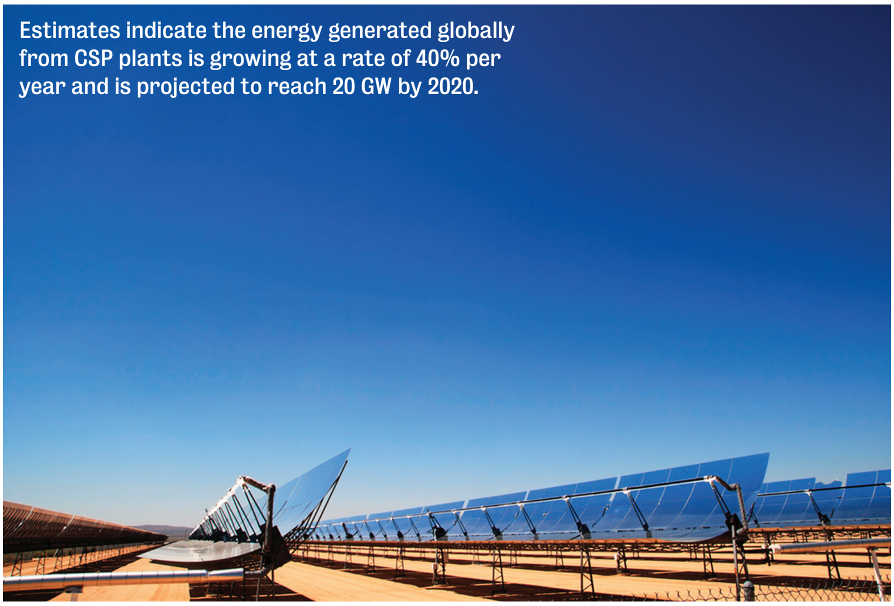

Estimates indicate the energy generated globally from CSP plants is growing at a rate of 40% per year and is projected to reach 20 GW by 2020.

Case study in CSP plant performance

USING ROUTINE sampling and chemical analysis of heat transfer fluid, early in a plant build, can help to extend the lifetime of CSP plants. Christopher Ian Wright BSc PhD MBA, explains.

It is estimated that the electricity generated globally from CSP plants is growing at a rate of 40% per year and is projected to reach 20 GW by 2020. Hence the number of new plants is expected to rise in the foreseeable future. The choice of heat transfer fluid (HTF) for CSP plants is important, and the commonly used HTF is a synthetic fluid with a eutectic mixture of diphenyl oxide and biphenyl. Synthetic HTFs are chosen for practical reasons, this being they operate up to 400 degrees Celsius, and for economic reasons. The current case demonstrates the importance of sampling and chemically analysing (SACA) synthetic HTFs throughout the life cycle of a HTF. This study shows that SACA needs to be considered to ensure the quality of the synthetic HTF on delivery to the client's site and also as a method to ensure that test parameters are within specification, and that measures are taken to ensure this is the case, once the HTF system has been filled with virgin synthetic HTF. Finally, the objective of SACA complements the commercial drivers for CPS plants and should be considered as an ongoing strategy to help reduce unexpected operational downtime; to help spread the cost of maintenance as test results can be used to predict potential problems and to make corrective plans as required; and to maintain the condition of the HTF and, therefore, help to extend the lifetime of the components of a CSP plant.

1. Introduction

Concentrating solar power (CSP) is a proven technology for electricity generation [AIS]. CSP plants generate electricity by transforming heat into mechanical energy using a steam turbine [1]. Since 2005 this sector has grown [2]. In 2008 CSP plants accounted for roughly 430 MW of the electricity generated globally [2]. The Australian Institute estimated that this was growing at a rate of roughly 40% per year and is projected to reach 20 GW of electricity being generated globally by 2020 [3]. In terms of the percentage of energy from CSP, it has also been estimated that it will contribute around 7% of the global power supply by 2030 and 25% by 2050 [2]. The factors driving these projections are varied and involve many factors, such as the price of oil, sustainable and secure energy supplies, rising pollution, greenhouse gases targets and the emergence of clean energy technologies [3].

With these forecasts it is no surprise there is a growing number of CSP installations with plants in Spain, the Southwest US and India [1], and the possibility of CSP plants being built in the Middle East and North Africa, Australia and South America [2, 3].

Fernandez et al. [4] investigated the corrosion properties of a ternary nitrate/nitrite molten salt in concentrated solar technology, and emphasised the importance of choosing the right heat transfer fluid (HTF). For The Jawaharlal Nehru National Solar Mission, the parabolic trough power plant was filled with a synthetic HTF with a eutectic mixture of diphenyl oxide and biphenyl [1]. This HTF provides an operating range between 12 and 400 degrees Celsius [1, 5].

Other factors to consider are the costs associated with operating and maintaining a CSP plant. Fernandez et al. [4] mentioned three areas where improvements are needed to increase the profitability of CSP plants. These were: i) to reduce investment in CSP plants and lower operational and maintenance costs; ii) to increase the temperatures in the thermal cycle and, therefore, the lifetime of the power plants; and iii) to extend operation time and thereby extend the period over which energy can be supplied.

Past research suggests that the condition of a HTF is influenced by the frequency that it is sampled and chemically analysed (SACA) [6]. This research demonstrated the importance of routine SACA and the need for an ongoing maintenance plan. This

Parameter	Description	
Appearance	Yellow liquid	
General description	Aromatic hydrocarbons	
Uses	Synthetic heat transfer fluid	
	Test Method	**Typical Data**
Upper operating temperature, °C	Defined in safety data sheet	400
Carbon Residue, % weight	IP14	ND
Strong Acid Number, mg KOH/g	IP139	0.0
Total Acid Number, mg KOH/g	IP139	<0.01
Closed Cup Flash Point, °C	ASTM93	113
Viscosity, mm^2/s (at 40 °C)	IP71	2.5
Open Flash Point, °C	ASTM92	ND
Fire Point, °C	ASTM92	ND
Water Content, ppm	ASTM D6304	<150
PQ (X1), Ferrous Debris Score	PQ Analex Method	10
FE, ppm less than 5 µm	ASTM D5185	0

Table 1. Typical uses, results and standard test methods for synthetic heat transfer fluid. Data is presented as mean±SD. # and **, P<0.05 and P<0.0001 when observed results were compared with expected results using a Chi-Square test. ND, no data reported in safety data sheet.

could be of benefit to CSP plants looking to reduce operational downtime, to spread the cost of maintenance plans and to extend the lifetime of the CSP plant.

This report presents the data from a case study where a plant was filled with a synthetic HTF with a eutectic mixture of diphenyl oxide and biphenyl [5], as is commonly used in a number of CSP plants. This case demonstrates the importance of SACA during the building of plants as well as on an ongoing basis.

2. Experimental methods

2.1. Client heat transfer fluid system

The current case concerns a company that was flushing and filling a plant with 100 metric tons of a synthetic HTF.

2.2. Synthetic heat transfer fluid

Global Group was contracted to fill the HTF system with a synthetic fluid with a maximal bulk temperature of 400 degrees Celsius [5]. Typical properties for the virgin synthetic HTF are reported in Table 1.

2.3. HTF system fill

The HTF system was newly built and prior to filling with a virgin HTF it was flushed with a fluid to remove all contaminants. The HTF system was then filled with a synthetic HTF according to standardised operating procedures and managed according to the safety data sheet.

2.4. Overview of filling procedure

Once the HTF system had been flushed, the flushing fluid was drained and the virgin synthetic HTF was pumped into the HTF system.

Prior to filling the HTF system the low, high and dump lines for the HTF system header tank were identified. They are then checked to ensure they are clear and that the synthetic HTF can flow through them. The filling procedure was initiated by attaching a suction pump and hose to the dump valve on the header tank so that the synthetic HTF can be drained from the HTF system and to allow air to be removed from the HTF system.

The valve from the header tank was then closed. The synthetic HTF was then pumped from the lowest point in the HTF system, through the heater coils, through the production line and then to the header tank. At this point, the dump valve is opened and filled to its minimum level (i.e., 50 to 200 litres depending on header tank volume) and that the HTF system is vented to prevent air from circulating through the HTF system, but also to ensure the synthetic fluid is properly vented and that any unwanted components are removed. Once circulation has been established, the heater is ignited and brought up to 125°C in a step-wise manner. This ensures that any moisture in the HTF system is boiled-off. Once this is done, the HTF system is ready to be run at normal operational temperature.

This case study demonstrates the importance of sampled and chemically analysed fluids during the building of concentrated solar power plants.

2.5. Synthetic HTF sampling

The synthetic HTF was sampled whilst the HTF was in circulation. These samples are then taken to the laboratory for subsequent chemical analysis. During sampling, 500 ml of the synthetic HTF was removed from the HTF system. This was performed using a closed sampling device to prevent the synthetic HTF coming into contact with air and therefore ensuring a representative sample of the synthetic HTF was taken. This technique has been presented previously [7, 8].

2.6. Chemical analysis of the synthetic HTF

All laboratory analysis was conducted according to ISO14001 [8] and ISO17025 [9]. The virgin synthetic HTF was sampled whilst in ISO storage tanks (3 samples were taken) and then after the HTF system had been

Test	Typical Data (i.e., expected results)	Pre-fill (n=3)	
		Mean±SD (i.e., observed results)	Variance±SD (%)
Carbon Residue, % weight	ND	0.02±0.01	16.67±14.43
Strong Acid Number, mg KOH/g	0.0	0.00±0.00	0.00±0.00
Total Acid Number, mg KOH/g	<0.01	0.04±0.01	6.61±5.73
Closed Cup Flash Point, °C	113	122.00±0.00	0.00±0.00
Viscosity, mm^2/s (at 40 °C)	2.5	ND	ND
Open Flash Point, °C	ND	128.67±3.06	0.04±0.03
Fire Point, °C	ND	139.33±3.06	0.03±0.03
Water Content, ppm	<150	209.33±34.36**	1.80±1.56
PQ (X1), Ferrous Debris Score	10	10.00±0.00	0.00±0.00
FE, ppm less than 5 µm	0	0.00±0.00	0.00±0.00

Table 2. Results obtained when the synthetic heat transfer fluid was chemically analysed prior to filling the clients HTF system. Data is presented as mean±SD. # and **, P<0.05 and P<0.0001 when observed results were compared with expected results using a Chi-Square test. ND, no data reported in safety data sheet.

filled (one sample was taken). This enables the values for a typical synthetic HTF to be compared with those taken during storage (i.e., pre-fill) and after filling the HTF system.

2.7. Data analysis

Microsoft Excel 2007 was used to calculate means, variances and standard deviations with a P-value <0.05 taken as an indication of statistical significance being achieved. Specific tests and comparisons conducted as outlined below.

2.7.1. Variance

Variance was calculated to provide an indication of the reproducibility of tests results. Variance was calculated using this equation: ([the sampled value—the group mean]/[the group mean])^2 and reported as a percentage [10].

2.7.2. Chi-Square test

A Chi-Square test [11] was used to assess the differences between observed values (i.e., those obtained prior to filling and whilst the synthetic HTF was stored in ISO tanks on the client's site) and expected values (i.e., values for the specific synthetic HTF used).

2.7.3. Z-test

Values recorded post-fill were compared with those obtained prior to filling using a Z-test [12]. This test compares sample and population means to determine if a significant difference exists.

3. Results

Results are defined according to the tests defined in the 'Data analysis' section above.

3.1.1. Variance

Percentage variance was calculated for all test values and was ≤2%. Carbon residue and total acid number had the highest variance, 16.67%±14.43 and 6.61%±5.73, respectively. Please see Table 2.

3.1.2. Chi-Square test

Analysis of synthetic HTF revealed no statistical difference (P>0.05) between sampled values and typical values, except for water content (P<0.0001; Chi-Square test) (Table 2). Mean water content, 209.33 ppm, was higher than defined in the safety data sheet (Table 1).

3.1.3. Z-test

Table 3 comparison of values recorded post-filling with those recorded pre-filling (i.e., whilst stored in ISO tanks). Carbon residue decreased slightly (from 0.02 to 0.01% weight; P<0.05) and water content decreased (from 209.33 to 150.00 ppm; P<0.05, Z test). Thus, water was equivalent to values reported typically for the synthetic HTF (i.e., estimated to be less than a 1% difference). Total acid number remained above the pre-fill and typical values for a virgin synthetic HTF (i.e., 0.10 versus 0.04 versus <0.01 mg KOH/g, respectively) although this was not significant.

4. Discussion

SACA is important in assessing the quality and condition of a synthetic HTF. With virgin HTFs it is imperative that the product is not contaminated during transport and filling of the HTF system. Standard operating procedures are used to ensure that the same process is followed every time. However, the current case highlights the importance of SACA, especially with the current synthetic HTF where the main contaminant appears to be water.

4.1. Pre-fill and post-fill values

This paper further highlights the importance of SACA of a HTF at every moment of its lifecycle. Data shows how important it is as a quality control measure, as was the case during storage and arrival on site, but also following a HTF system build.

> Past research has shown that the overall condition of a mineral-based heat transfer fluid is better when it is sampled and chemically analysed more frequently.

This primarily done to ensure that the synthetic HTF is not contaminated during transport or by materials that may accumulate in a HTF system whilst being built. Ideally, flushing with Globaltherm™ C1 [13], should be used to clear debris from a system and avoid contamination of a virgin heat transfer fluid.

Table 2 shows that water differed significantly from expected values. Mean closed flash point temperature was 122.00°C and above the value defined for a typical synthetic HTF (i.e., 113°C). This is not an issue as the value was above 113 °C and only a problem if closed flash point temperature drops below 113°C. In the latter case, the "light-end" fractions would be accumulating in the HTF and would be a sign of thermal degradation. In such cases, there are a number of options for managing flash point temperature, such as the installation of mobile or permanently fitted light-end removal kits, which help to keep closed flash point temperature stable [10].

Mean water level was higher than reported in the safety data sheet. It was +39.6% higher (209 vs. 150 ppm; Table 3). However, the standard operating procedure, briefly outlined in the Experimental Methods, section does highlight the importance of removing water on filling the HTF system. This was the case herein, as post-filling with the synthetic HTF water was 150 ppm, which is the value defined in the safety data sheet (Table 3).

After the HTF system was filled, total acid number was 1.0 mg KOH/g which was higher than the pre-fill value (0.04 mg KOH/g) and the typical value (<0.01 mg KOH/g), although there was no statistical difference. The figure recorded post-fill is has not significant impact on the HTF system as it is normally recommended to maintain total acid number below 0.2 mg KOH/g [14].

		Pre-fill (n=3)	Post-fill (n=1)
Test	**Typical Data**	**Mean±SD**	**Mean**
Carbon Residue, % weight	ND	0.02±0.01	0.01†
Strong Acid Number, mg KOH/g	0.0	0.00±0.00	0.00
Total Acid Number, mg KOH/g	<0.01	0.04±0.01	0.10
Closed Cup Flash Point, °C	113	122.00±0.00	124.90
Viscosity, mm^2/s (at 40 °C)	2.5	ND	ND
Open Flash Point, °C	ND	128.67±3.06	NA
Fire Point, °C	ND	139.33±3.06	NA
Water Content, ppm	<150	209.33±34.36	150.00‡
PQ (X1), Ferrous Debris Score	10	10.00±0.00	10.00
FE, ppm less than 5 μm	0	0.00±0.00	0.00

Table 3. Results obtained when the synthetic heat transfer fluid was chemically analysed after being filled. Data is presented as means and mean±SD. † and ‡, P<0.05 and P<0.005; Z test comparing post-fill with pre-fill. NA, not analysed. ND, no data reported in safety data sheet.

4.2. Variance

The data provides insights to the reliability of measurements. This was not the primary aim of this study, but it is important as both accurate and regular SACA of a HTF [3] is critical in assessing both current and future HTF condition. Data shows that the percentage variance was ≤2% for all test parameters prior to filling. This was also true for the virgin synthetic HTF with the only exception being carbon residue and total acid number where percentage variance was 16.67% and 6.61%, respectively. However, in both cases the values were close to zero (mean: carbon, 0.02±0.01%; and, total acid number, 0.04±0.01 mg KOH/g), and so small variations have significantly influenced the calculation for variance.

4.3. Future research

It is important to know how reproducible test methods are in the laboratory. Variance is affected by both intra and inter-test variation, which is, in turn, potentially influenced by the operator. In this case, the engineer taking the sample. The current data highlights that there is generally a small amount of variance, which suggests that the tests reports have good reproducibility. However, this is one area where future research is needed both for mineral-based and synthetic HTFs.

5. Conclusions

The key message from this report is that HTFs need to be analysed routinely. Indeed, past research has shown that the overall condition of a mineral-based HTF is better when it is sampled and chemically analysed more frequently. This, therefore, underlines the importance of SACA. The new insight from this report relate to the fact that the synthetic HTF used herein is commonly used in the CSP plants and its water content therefore needs to be monitored. This is particularly important during its storage to ensure it is within the specifications of the limits defined in the safety data sheet, as well as during any intervention where the HTF system is open to atmosphere as may occur during HTF system maintenance, and as part of an ongoing maintenance program to monitor the condition of the HTF.

Lastly, an ongoing SACA plan is important for maintaining the condition of a HTF. This is of potential value to CSP plants, helping to reduce unexpected operational downtime as well as helping to spread maintenance costs as test results can be used to predict potential problems and to plan corrective actions at a time that is most convenient to the client. Finally, to maintain the condition of a HTF and therefore help to extend the lifetime of the components of a CSP plant.

Acknowledgements

The author would like to acknowledge the Global Heat Transfer engineering and technical support teams.

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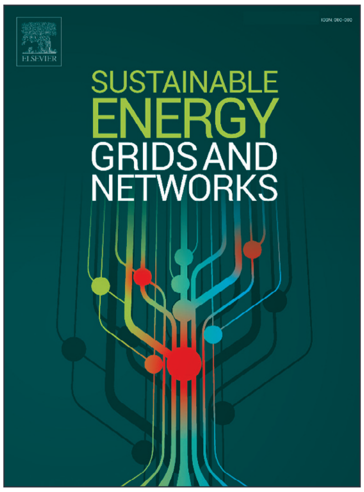

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