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The relationship between the condition of a mineral-based heat transfer fluid and the frequency that it is sampled and chemically analysed

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HIGHLIGHTS

- The frequency that a heat transfer fluid (HTF) is sampled may correlate with its condition.
- This retrospective study looked the aforementioned linear relations.
- No significant correlation existed between HTF sampling frequency and HTF condition.
- When condition accounted for sampling frequency, a relationship was confirmed.
- Clearly the condition of an HTF is better controlled when sampled regularly.

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ABSTRACT

A large number of industrial processes require the efficient transfer of heat energy. Heat transfer fluids (HTFs) are imperative in such processes. The efficient transfer of heat energy is affected by system fouling and past studies have mainly focused on the fouling of heat exchangers but not the overall system. In normal operations HTFs are routinely sampled and chemically analysed to get an insight into the condition of both the HTF and the heat transfer system. The aim of routine maintenance programmes is to sustain normal operation and slow the rate of thermal degradation. HTF analysis is used to assess the chemical by-products of thermal degradation and oxidation. It is also used to detect system wear particles, water and contamination. Manufacturers often recommend that an HTF is analysed at least once per year. To date, however, it is unclear if this is the optimal sampling frequency. The current study investigated if sampling frequency had any bearing on the overall condition of mineral-based HTFs. Results revealed that parameters of HTF condition were inversely related to sampling frequency with increases in sampling frequency being correlated with improvements in overall HTF condition. This implies that frequent sampling works to improve the health of mineral-based HTFs. The implication being that a mineral HTF should be assessed as frequently as possible. Furthermore, when systems are sampled regularly (i.e., $\geq$1 per year), total acid number and closed flash temperature need to be monitored closely as these were most frequently out of specification when sampled between once per year and four times per year.

1. Introduction

A large number of industrial processes require the transfer of heat energy between a heat transfer fluid (HTF) and processing equipment [1]. With time HTFs thermally degrade, which is a complicated chemical process [2] influenced by a wide variety of intrinsic factors, such as operating temperature, and extrinsic factors, such as contamination by water [3].

One aspect of thermal degradation is system fouling. This is where organic matter, scale, corrosion products, coke, particulates

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Abbreviations: HTF, heat transfer fluid; SACA, sampling and chemical analysis; TAN, total acid number; CFT, closed flash temperature; OFT, open flash temperature; IP, institute of petroleum; ASTM, American standard test method; KOH/g, potassium hydroxide per gram; ppm, parts per million; Fe, iron; Si, silicon.

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and other deposits, settle on a heat transfer surface and impair heat exchanger performance and efficiency [1]. In every day practise, system fouling is assessed from intermittent sampling and chemical analysis of system's HTF [4]. Chemical analysis involves the measurement of coke and flash temperatures [5] as well as the assessment of thermal oxidation (based on the total acid number), HTF viscosity, system wear particles and the presence of water/foreign particulates [4]. All laboratory analysis is conducted according to industry standards (i.e., ASTM and IP) and test results indicate if a test parameter is in or out of specification. In the case that a test parameter is out of specification, a rating is assigned based on severity. For example, a caution rating or an action rating in the event of more severe out of specification ratings. Test reports therefore provide insight into the number and extent of parameters that are in or out of specification at any given time point.

HTF manufacturers commonly recommend that HTF sampling and chemical analysis (SACA) is conducted annually when an HTF is operating near its upper operating temperature or bi-annually if operating ≥20 °C below the upper its operating temperature [6]. Annual SACA is also recommended by the companies insuring HTF systems [7]. Interestingly, however, there is no published data to indicate the optimal SACA frequency for mineral HTFs. This is the first study seeking to assess the optimal frequency that an HTF should be assessed. This study sought to address this question by investigating the correlation between sampling frequency and HTF condition, assessed from historical analysis reports. The objective being to define what is the optimal sampling frequency for a mineral HTF.

2. Methodology

2.1. Test data

Historical test reports were analysed. Analyses focused on test reports sampled in the same year and that were sampled once, twice or four-times per year. The database of test reports was also searched to identify systems where sampling had been missed one year prior (i.e., one report every 2 years) and two years prior (i.e., one report every 3 years). This approach identified only two test reports, so the search was extended to include all previous years. In total, five sampling frequencies were captured.

2.2. Parameters measured and typical values for mineral-based heat transfer fluid

Carbon residue, total acid number (TAN), closed flash temperature (CFT), open flash temperature (OFT), kinematic viscosity, water content, ferrous wear debris (insolubles) and elements (e.g., iron and silicon) were routinely tested in all test reports identified in the test report database.

Table 1 summarises the eight test parameters and the test methods conducted. In the current analyses, parameters were rated. A satisfactory rating was assigned if the parameter was within normal limits and therefore assigned a ‘zero’ score. A caution rating represented an out of specification and was assigned a score of ‘1’. Finally, an action rating was assigned a score of ‘2’ if the parameter was seriously out of specification.

The product of this scoring method is that the number of observations, either in or out of specification, multiplied by the test score. The maximum score per test report being a score of 16' and the lowest score being ‘0’.

2.3. Analysis parameters

The following parameters were measured directly from test reports:

1) The sampling frequency.
2) The total test report score.
3) The number of observations.

The above parameters were used to calculate the following variables:

i. The total test report score per observations [i.e., 2) divided by 3) above].
ii. The total test report score per sample frequency [2) divided by 1)].
iii. Observations per sample frequency [3) divided by 1)].
iv. Observations per total test report score [3) divided by 2)].

2.4. Data analysis

Data are reported as mean ± standard deviation (SD) unless otherwise stated.

Within each group, means were compared using a two-tailed, unpaired t-test. This was conducted using Microsoft Excel 2007. All values were compared with the reference value, taken as the least sampled group (i.e., once every three years).

Within each group, the mean value for each parameter/calculated variable was plotted against sampling frequency. A sample frequency of 3 indicates that one sample was taken every 3 years; 2, that 1 sample was taken every second year; 1, that one sample was taken in a year; 0.5, that 2 samples were taken in one year; and, 0.25, that 4 samples were taken in one year.

A Pearson correlation coefficient (r) was fitted to determine if plotted parameters were linearly related and significance of this correlation was tested using Analyse-it® version 3.71. The Pearson correlation coefficient is a measure of the linear correlation between two variables X and Y. Values between $+1$ (total positive correlation) and -1 (total negative correlation) is reported. No correlation is indicated by a zero value.

Statistical significance was taken as $P < 0.05$.

3. Results

A total of 168 systems were analysed and these systems contained mineral-based HTF. The sampling frequency and the number of systems sampled is summarised in Table 2.

A significant proportion of systems were analysed and scored as satisfactory. Based on sampling frequency this breaks down as follows: 25.0% when sampled every 3 years; 62.2% every 2 years; 57.5%, every year; 57.4% every 6 months; and, 37.9% every 3 months.

Table 1
Test parameters routinely measured and the sample rating system used.

Test parameter, unit or element	Test method	Typical value[a]	Sample rating		
			Satisfactory	Caution	Action
Carbon residue, % weight	IP14	<0.05	≥0.05–<0.5	≥0.5–<0.75	≥0.75
TAN, mg KOH/g	IP139	<0.05	≥0.05–<0.2	≥0.2–<0.4	≥0.4
CTF, °C	ASTM D93	210	≤210–>130	≤130–>110	≤110
OFT, °C	ASTM D92	221	≤221–>160		≤160
Kinematic viscosity, mm^2/s	IP71	31	±5% change	±10% change	>10% change
Water content, ppm	ASTM D6304	<100	≥100–<300	≥300–<500	≥500
Ferrous wear debris (insolubles)	PQ Analex Method	<10	≥10–<20	≥20–<40	≥40
Elements (e.g., Fe, Si)	ASTM D5185	0	≥0–<40	≥40–<100	≥100

[a] Typical safety data sheet. Satisfactory, caution and action ratings are based on the rating system used by Global Heat Transfer to assess the status of a mineral-based HTF.