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Short Communication

On the use of the Arrhenius equation to describe the impact of temperature on grease life

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ABSTRACT

The most commonly used equation that is used to describe the temperature dependency of chemical reaction rates is the Arrhenius equation. The impact of temperature on grease life is usually not described using the Arrhenius equation but by a more "contemplative" equation. In this note the equations will be compared and it will be shown that these are almost identical despite the apparent "engineering character" of this equation. This should remove any doubts to use this equation.

1. Introduction

Grease degradation is often considered a chemical process where the use of an Arrhenius equation to describe the impact of temperature seems to be obvious. The appearance of an activation energy and Bolzmann constant in the equation suggests "a scientific approach" as opposed to the generally used equation that is used in the grease and bearing industry where impact of temperature on grease life is described using a simple exponent, which is more "contemplative": grease life halves with a temperature increase of T_A degrees. This concept is less abstract and easier to use. There is however often discussion on the correctness of this. This short communication report will show that both methods are essentially equal.

2. Grease life following the Arrhenius equation

If we assume that grease life follows pure Arrhenius behavior, grease life L at temperature T can be written as

$$L = L_r \exp\left(\frac{E_a}{RT}\right) \tag{1}$$

Here E_a is the activation energy [J/mol]. L_r a reference life [h]. The temperature T has unit Kelvin [K]. The gas constant R=8.31 J/(K mol). Grease life with life L_1 at temperature T_1 then reads:

$$L_1 = L_r \exp\left(\frac{E_a}{RT_1}\right) \tag{2}$$

and grease life with life L_2 at temperature T_2:

$$L_2 = L_r \exp\left(\frac{E_a}{RT_2}\right) \tag{3}$$

The ratio of the lifes gives:

$$\frac{L_1}{L_2} = \exp\left(\frac{E_a}{RT_1} - \frac{E_a}{RT_2}\right) \tag{4}$$

or

$$\frac{L_1}{L_2} = \exp\left[\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \tag{5}$$

and the activation energy then can be calculated form the results of two tests, done at temperatures T_1 and T_2 according to:

$$E_a = \frac{T_1 T_2}{T_2 - T_1} R \ln\left(\frac{L_1}{L_2}\right) \tag{6}$$

3. Grease life following the engineering approach

The commonly used grease life models [1–4] show that grease life increases with a factor 2 by decreasing the temperature with what we call the "Arrhenius temperature" T_A (which is in [5] equal to T_A = 15 °C; note that, since this is a temperature difference, the unit can be Kelvin or Celsius). For an extensive description of this Arrhenius temperature concept the reader is referred to [6]. This rule of thumb can be written as:

$$\frac{L}{L_r} = 2^{\frac{T_r - T}{T_A}} \tag{7}$$

or grease life at temperature T is

$$L = L(T_r)\, 2^{\frac{T_r - T}{T_A}} \tag{8}$$

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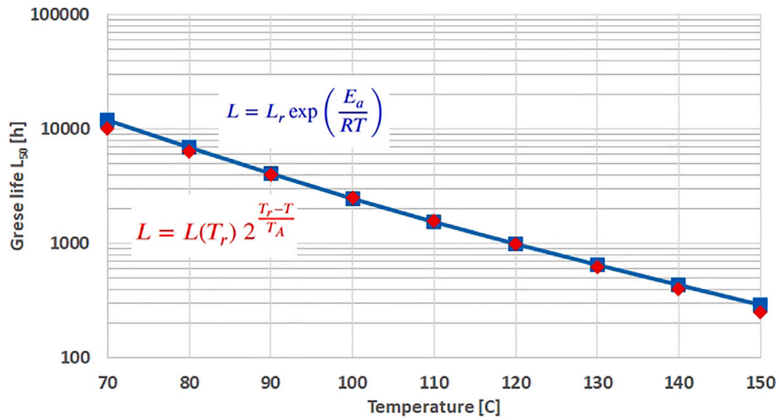

Fig. 1. Grease life versus temperature using the Arrhenius equation and by using the engineering approach with $T_A = 15$ °C.

where $L(T_r)$ is grease life at $T = T_r$. The Arrhenius temperature can therefore, similar as for the activation energy Eq. (6) be calculated from the results of two tests:

$$T_A = \ln 2 \frac{T_2 - T_1}{\ln L_1 - \ln L_2} \tag{9}$$

4. Comparing the two models

Combining Eqn (5) and (7) gives:

$$\frac{L_1}{L_2} = 2^{\frac{T_2 - T_1}{T_A}} = \exp\left[\frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \tag{10}$$

or

$$\frac{T_2 - T_1}{T_A} \ln 2 = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \tag{11}$$

or

$$E_a = \frac{T_1 T_2}{T_A} \cdot R \ln 2 \tag{12}$$

Eq. (12) gives the relation between the activation energy E_a and the Arrhenius temperature T_A. It contains two temperatures T_1 and T_2, the temperatures that are used to determine *both* E_a and T_A. So if the "engineering rule" is used the activation energy is a function of the temperature. We will see in the next section that the two approaches give almost the same result.

5. Practical example

In order to relate the activation energy E_a to the Arrhenius temperature T_A we need to select the two temperatures at which there will be an exact match in grease life. The "green zone" in grease life is usually somewhere between 50 and 150^oC. So a good selection would be $T_1 = 80$ °C (so $T_1 = 353.15$ K) and $T_2 = 140$ °C (so 413.15 K). Now with $T_A = 15$ °C, Eq. (12) then gives an activation energy $E_a = 5.60 \times 10^4$ J/mol.

Let us assume that we have a grease that gives a grease life of 1000 h at 120 ° C. Then by using Eq. (1) this gives $L_r = 3.57 \times 10^{-5}$ h. Fig. 1 shows the result. The Arrhenius correction, Eq. (7), does not give exactly the same result as the Arrhenius Eq. (1). It is an approximation, an engineering approach. In [5] we fix T_A to $T_A = 15$ K. Fig. 1 shows that it is quite good. This approach is preferred because it gives approximately the same result and it avoids using an abstract activation energy concept.

6. Conclusions

Grease life is generally described using a simple Arrhenius equation where the resistance to degradation of a lubricating grease is characterized by an Arrhenius temperature T_A as

$$L = L(T_r) \cdot 2^{\frac{T_r - T}{T_A}} \tag{13}$$

This factor depends on the grease type and is typically $10 \le T_A \le 20$, see Ref. [6]. The beauty of this simple equation is its simple interpretation: grease life doubles with every T_A temperature decrease. This is preferred over the conventional formulation where an activation energy is used to characterize grease life versus temperature. The Arrhenius temperature is around $T_A = 15$°C for most greases. This gives an activation energy of $E_a = 5.6\times10^4$ J/K/mol, which is a number that does not give an obvious interpretation for the correlation between grease life and temperature. The formulation using the activation energy suggests a higher accuracy or a formulation based on "first principles". It is shown here that formulation (13) gives almost identical results. Both functions can be used to describe the relationship between grease life and temperature well.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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