Calculation of Sensor Spacings

Scope

The latest Fire Prevention Plan (FPP) Guidance contains a requirement to:

> "monitor subsurface temperature with a probe or other device that can take representative readings from the centre of a pile"

This is a key control measure in ensuring that the objective to:

> "minimise the likelihood of a fire happening"

is achieved.

In order to adhere to the requirements of the FPP guidance, site operators must devise a monitoring protocol which can be demonstrated to produce representative readings from the material being monitored.

What constitutes "representative readings" depends on the nature of the material being monitored and the design / operation of the storage system. Woodchips / hog fuel materials are known to self-heat in a fairly irregular fashion so several monitoring points are required to determine the hottest area of a stockpile, and therefore the area most at risk of spontaneous combustion. There is no explicit requirement in the FPP guidance to be able to identify the exact location of a hot-spot, but this is clearly an advantage in meeting the objectives of the guidance, as it allows for corrective action to be taken when required to minimise the likelihood of a fire happening.

To ensure that any monitoring protocol is effectively collecting representative data, some background knowledge of the material is required. Monitoring protocols should be regularly reviewed, using collected data, to ensure that the data would be considered representative.

The PREVENTiT Temperature Monitoring String System

This system was devised to provide a monitoring solution for long-term storage of stockpiled material. The system comprises a series of cables containing a number of sensors at know positions along the string. The strings are buried into the stockpiles as the piles are constructed. Data collected from the sensors are transmitted wirelessly back to the site computer from where they are uploaded onto an online database for subsequent viewing and analysis. Alarm threshold levels can be set to alert operators of a potential self-heating risk so preventative action can be taken.

Monitoring Protocols

Sensor Spacing

The sensor spacing should be chosen to ensure that a gradual trend can be observed along the length of the string: this implies that no hot / cold spots are being missed between sensors. An example showing the effects of inadequate sensor spacing can be seen in Fig. 1 and Fig. 2. The system with inadequate sensor spacing is likely to underestimate the true temperature of the hottest part of the pile.

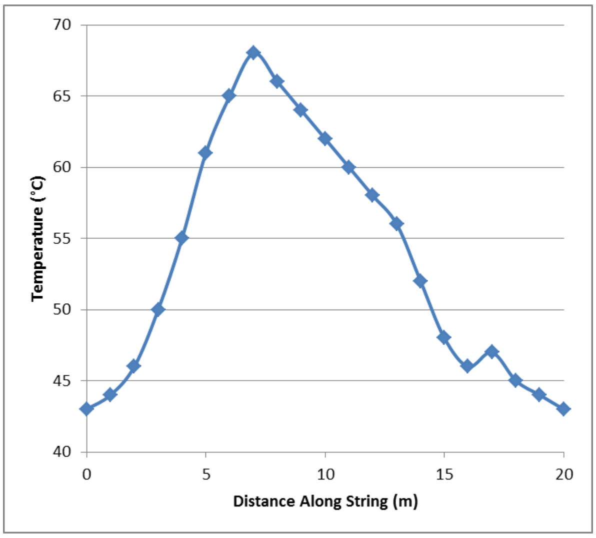

Fig. 1. Example showing adequate / excessive sensor spacing.

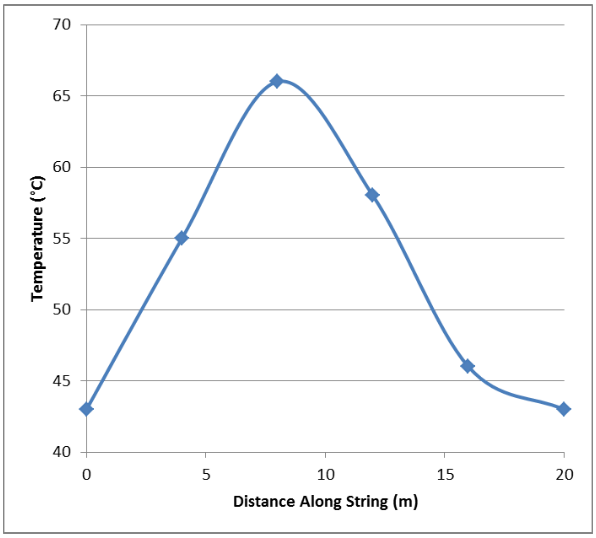

Fig. 2. Example showing inadequate sensor spacing.

Sensor Placement

Sensors should be placed as close as possible to the highest-risk area of the stockpile being monitored. For most piles, this is the very centre of the pile, although this may not always be the case. The number and positioning of strings will affect the distance between any given part of the pile and its nearest sensor. This ‘furthest distance from sensor’ parameter (D_F) is defined as the maximum linear distance between any part of the stockpile and a temperature sensor. This parameter can be calculated geometrically for any size pile / string arrangement.

To assist with defining this parameter, a set of nominal axes can be defined for a stockpile with strings running longitudinally through it (Fig. 3): this considers the centre back of the pile, at ground level to be the origin (x=y=z=0).

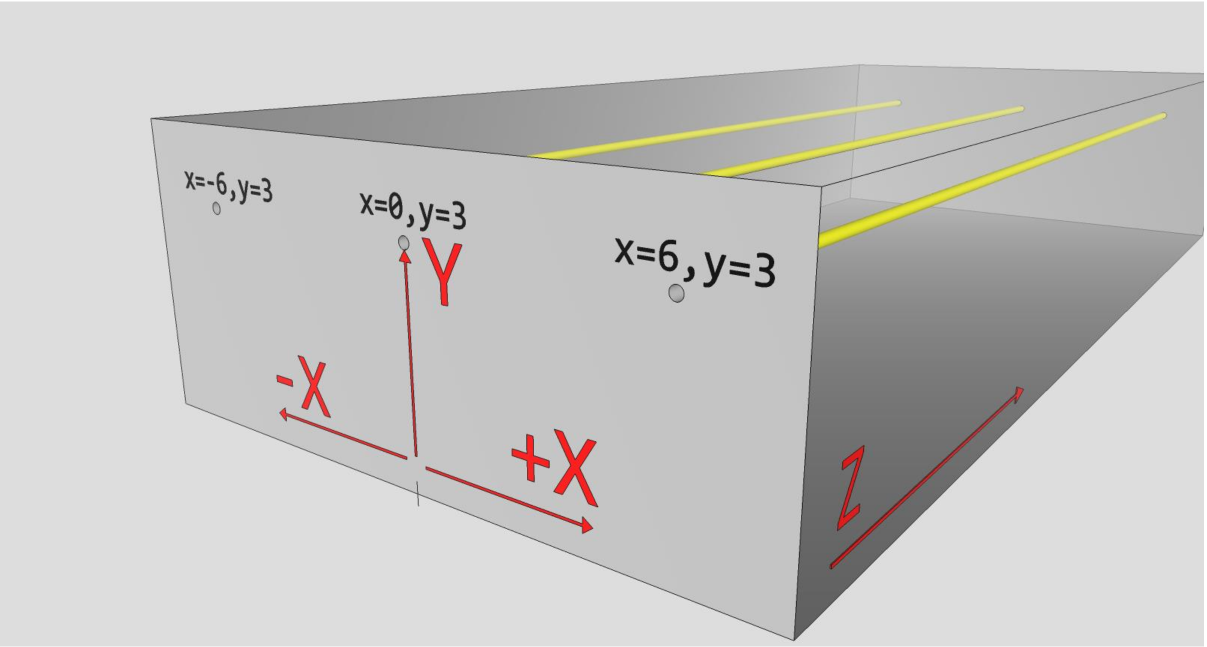

Fig. 3. Definition of axes.

PREVENTiT strings are designed with a sensor on either end of the pile, then a regular spacing (D_S) of sensors in between each end. For example, a 20m long string with a 2m spacing would contain 11 sensors, spaced at 2m intervals.

To simplify the calculations, it is assumed that the strings are spaced evenly across the X axis of the pile, and spaced evenly along the Y axis; this would also be the most logical way to position the strings, as it aims to reduce D_F.

The horizontal string spacing, D_x is determined by dividing the pile width, W, between the number of strings used on each layer, n_x plus one, according to Equation 1.

$$D_x = \frac{W}{n_x + 1}$$

Equation 1. Definition of horizontal sensor spacing, *Dx*

Similarly, the vertical string spacing , D_y is determined by dividing the pile height, H, between the number of layers of strings used, n_y plus one, according to Equation 2

$$D_y = \frac{H}{n_y + 1}$$

Equation 2. Definition of vertical sensor spacing, *Dy*

In order to calculate D_F, first, the furthest distance on the X-Z plane (viewed from above, D_{xz}) needs to be calculated. This will be the distance of the mid-way point between sensors to the outer edge of the pile; this is illustrated by Fig. 4 and calculated in Equation 3.

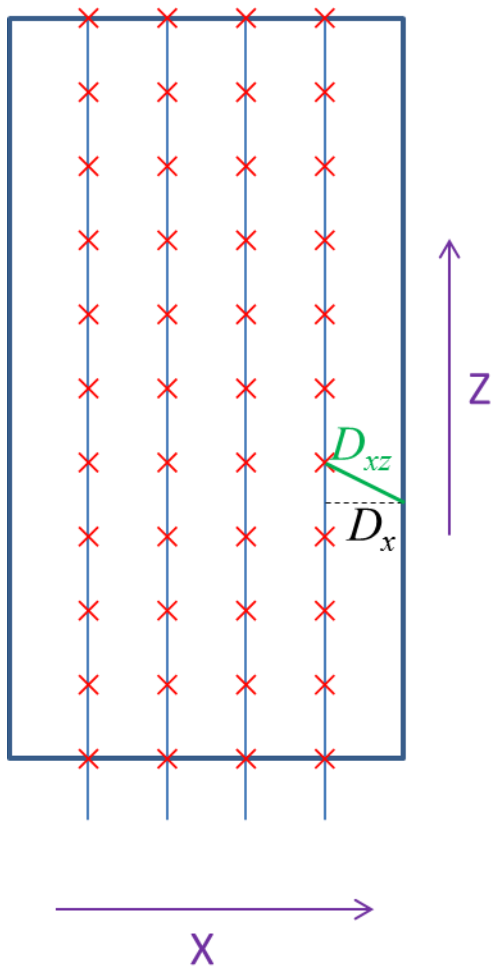

Fig. 4. Definition of maximum X-Z planar distance, D_{xz} [Viewed from Above]

$$D_{xz} = \sqrt{\left(\frac{D_s}{2}\right)^2 + D_x{}^2}$$

Equation 3. Calculation of maximum horizontal planar distance.

The next step is to calculate the vertical distance (in the X-Y plane) between the sensor and the furthest part of the material, using the result from the previous calculation (D_{xz}) as one of the legs of the triangle, and the vertical sensor spacing (D_y) as the other; the hypotenuse of this triangle is the maximum sensor distance (D_F).

$$D_F = \sqrt{D_y{}^2 + D_{xz}{}^2}$$

Equation 4. Calculation of maximum sensor distance.

Worked Example

Inputs

- Bay 20m wide (W=20)
- Sensor spacing of 2m (D_s=2)
- One layer of strings per bay (n_y =1)
- Bay filling height of 4m (H=4)
- Four strings per layer (n_x = 4)

Calculation

$$D_x = \frac{W}{n_x + 1}$$

$$D_x = \frac{20}{4 + 1}$$

$$D_x = 4\text{m}$$

$$D_y = \frac{H}{n_y + 1}$$

$$D_y = \frac{4}{1 + 1}$$

$$D_y = 2\text{m}$$

$$D_{xz} = \sqrt{\left(\frac{D_s}{2}\right)^2 + {D_x}^2}$$

$$D_{xz} = \sqrt{\left(\frac{2}{2}\right)^2 + 4^2}$$

$$D_{xz} = \sqrt{1 + 16}$$

$$D_{xz} = \sqrt{17} = 4.12\text{m}$$

$$D_F = \sqrt{2^2 + 4.12^2}$$

$$D_F = \sqrt{4 + 17}$$

$$\boldsymbol{D_F = \sqrt{21} = 4.58\mathrm{m}}$$

Therefore, if four strings with a 2m sensor spacing are placed along the middle of a bay filled to 4m high, the maximum distance from any part of the stockpile to its nearest sensor is around 4.6m.