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P2_5 Wiggle Your Washing Dry!

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Abstract
An investigation is conducted to determine what frequency one would need to wiggle a washing line at, in order for the wave to provide enough energy to dry a sheet. For a modelled line it is found that a frequency of around 324 Hz would be needed for 0.1m amplitude of oscillation. A more realistic frequency of 5Hz would require an amplitude of 6.47m.

Introduction

Many would agree that waiting for clothes to dry is a long and unexciting process. This paper investigates whether drying your clothes could be done in a more entertaining manner by wiggling your washing line. Wave theory together with heat transfer physics is used to discover a possible suitable frequency that you could oscillate your washing line at, in order to provide the energy needed to evaporate the entire water content of a wet double bed sheet.

Motion of the Washing Line

The motion of a washing line is assumed to be that of a standing wave, and hence it is assumed that either end of the line is effectively fixed. The line is under a tension, provided by the weight of a mass, M, as shown in Figure 1. The washing line is taken as idealised i.e. it has a Young's modulus of zero, which means there is no increase in the local tension of a string due to a change in the displacement of the wave from zero amplitude [1].

A person is assumed to produce the standing wave by wiggling the string at location B as shown in Figure 1. The length of the line under motion is L. It can be shown that the total energy (kinetic and potential energy), E, of the standing wave fixed at both ends [1] is given by,

$$E = L\pi^2\eta f_n{}^2 A^2, \quad (1)$$

where η is the mass per unit length of the string, f_n is the resonant frequency for the nth harmonic of a standing wave, and A is its amplitude. This paper does not consider the transfer of energy from the wave into the thermal vibrations of the water molecules that would occur by damping in the string. It merely determines if the wave has enough energy to enable the process. All other mechanisms of water loss from and heat transfer to the sheet are neglected. This simple model assumes no damping due to air drag.

Although the bed sheet would be hanging from the washing line, this situation is simplified to having the sheet wound around it. This increases η and its cross-sectional area. The final thicker line is also taken as idealised.

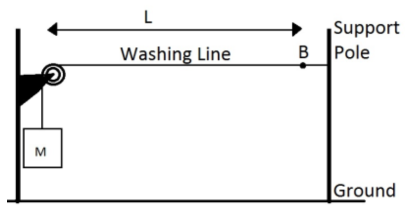

Figure 1: Showing the washing line scenario. B is the location of 'wiggle' motion.

Evaporating Energy

The bed sheet has a dry mass, $m_{d\ bs}$, and a wet mass, $m_{wet\ bs}$, where their difference is the mass of the water, m_w, contained in it. The absorbency of a linen sheet is not known, thus in order to gain an estimate of this mass experimentally determined values of a small quantity of wet and dry linen were used to estimate a mass increase of around 35% when wet. Therefore the wet mass of a sheet was estimated as 0.92 kg for a measured dry mass of around 0.68 kg. These figures are taken as examples for a double bed sheet; in practice they would vary depending upon the washing machine settings, the bed sheet size and material. The mass of water, m_w, contained in this example bed sheet is 0.24kg.

The energy, Q, required to evaporate this mass of water is given by,

$$Q = m_w L_v, \tag{2}$$

where L_v is the latent heat of vaporisation. A material can evaporate at any temperature provided there is enough energy to disassociate all of its molecules from a liquid state into a gas. L_v is typically stated for a boiling point temperature; at lower temperatures L_v is greater than this value [2]. An ambient temperature of 25 °C is assumed where L_v is equal to 43 932 J kg $^{-1}$ [2].

Wiggling Frequency

The aim was to find the frequency, for a given amplitude, in order for the standing wave to provide enough energy for all of the water to evaporate i.e. for if the total wave energy, as stated in Equation 1, could be utilised.

By equating Equation 2 to Equation 1, and rearranging, the following is found,

$$f_n = \sqrt{\frac{m_w L_v}{L\pi^2 A^2 \eta}}. \tag{3}$$

In order to estimate a frequency of oscillation, the following assumptions are made for the various parameters. The length, L, of the wave in motion is taken as 5 m, and the bed sheet is assumed to be the same as the example double bed sheet, giving the mass of water contained within it, m_w , as 0.24 kg. The mass of the washing line, m_{line}, is taken to be 0.1 kg. The mass of the wet bed sheet, $m_{wet\ bs}$, is equal to 0.92 kg. By considering L and the sum of m_{line} and $m_{wet\ bs}$, a mass per unit length, η, of 0.204 kg m^{-1} is calculated. The amplitude of the wave is assumed to be 0.1 m. Equation 3 thus estimates a frequency of around 324 Hz.

It would be unfeasible for a person to oscillate a washing line with their hand at such a frequency. Assuming that a person could achieve around 5Hz, the corresponding amplitude of oscillation which could provide this is sought. Equation 3 is rearranged to find that an amplitude of 6.47 m would be needed!

Conclusion

The frequency required for a person to wiggle a washing line, for an amplitude of 0.1m , was found to be humanly impossible, and an amplitude of around 6.47 m would be required if a person were able to oscillate the line at a more appropriate 5Hz.

It would be possible to oscillate the washing dry with an electrically powered mechanical driver at around 324 Hz, with an amplitude of 0.1 m. Future investigations could consider the details of the damping process in the line. They could also consider the cost implications of using a mechanical driver compared to a tumble drier.

References

[1] W. Elmore and M. Held, *Physics of Waves*, (Dover Publications Inc., New York, 1985), 1st ed., p. 31-36

[2] A. Cottrell, *The Mechanical Properties of Matter*, (John Wiley & Sons, Inc., New York, 1964), 1st ed., p. 33-36