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Mechanical Engineering

INFRARED THERMAL AND VISUAL IMAGE ANALYSIS FOR THE MODELLING OF PROPERTIES IN CASCADING PARTICLE CURTAINS

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Contents

1 Introduction

Understanding temperature distributions in Engineering applications plays an invaluable role toward understanding the effectiveness of design. As one of the most frequently measured physical quantity, the quantification of temperate values and their distributions allows for design goals to be achieved in a far more succinct manner and plays a key role in a diverse range of engineering systems. One particularly challenging engineering process that proves problematic in obtaining thermal data for is the particle curtain.

Particle curtains are defined as a stream of particles falling a fixed distance through a gas or fluid phase [1]. They are very common in industrial drying, particularly in the minerals and food industry [1]. Furthermore, particle curtains are steadily emerging in promising new renewable energy technologies for use in concentrating solar power (CSP) plants. These solar particle receiver designs are currently in the early demonstration phase, delivering improved thermal efficiency through their direct storage of heat within sand-like particles [2, 3]. With regards to the Industrial and Mineral Industries a common technique for particle drying is the use of Flighted rotary dryers (FRD). Flighted rotary dryers are used extensively in a large range of industries for the control of temperature and moisture content of free flowing, particulate solids such as grains, sugar and mineral ores [4]. However, Whilst flighted rotary dryers are widely used, their complex solids transport behaviour, and the difficulty of separating solids transport and heat and mass transfer phenomena within the dryer, has proven to be a significant issue in regards to understanding their behaviour. Given the complex behaviour of flighted rotary dryers, and the lack of design and control procedures, there is a need for a model for flighted rotary dryers [4].

Currently there are two major branches of research being conducted on particle curtains. The first is of which relates to computational modelling of particle curtains, one of which is the development of Computational Fluid Dynamics (CFD) based models. CFD has been applied successfully to model particle curtains in isothermal conditions; however, there are relatively few CFD studies of hot particle curtains. Furthermore, the use of CFD to approximate bulk curtain behaviour has not been described [1]. Another of these methods relates to DEM

1.1 Objectives

develop a numerical/analytic model to represent the thermodynamic properties of a particle curtains through the combination of known kinematics, thermodynamic properties. Verifying these relations through the analysis of IR and VIS imagery.

2 Literature Review

2.1 Introduction

In this Literature Review, a general description of the physical nature of particle curtains and the relevance of particle curtains in real world applications will be looked at along with the current modelling techniques used to describe their behaviour, furthermore the fundamental thermodynamic heat transfer relationships will be looked at along with how these relations affect a falling particle curtain.

In addition to this Infra-red Thermal Imaging will also be looked at which will also cover current relevant Image analysis/processing and statistical analysis techniques. Further more camera modelling along with model building techniques will also be looked at.

2.2 Particle Curtains

Particle curtains are defined as a stream of particles falling a fixed distance through a gas or fluid phase [1]. Within this process a complex exchange of heat mass transfer occurs in a multiphase system. Particle curtains are very common in industrial drying, particularly in the minerals and food industry [1].

A common technique for particle drying is the use of Flighted rotary dryers (FRD). Flighted rotary dryers are used extensively in a large range of industries for the control of temperature and moisture content of free flowing, particulate solids such as grains, sugar and mineral ores [4]. However, Whilst flighted rotary dryers are widely used, their complex solids transport behaviour, and the difficulty of separating solids transport and heat and mass transfer phenomena within the dryer, has proven to be a significant issue in regards to understanding their behaviour. Given the complex behaviour of flighted rotary dryers, and the lack of design and control procedures, there is a need for a model for flighted rotary dryers [4].

In addition to their use in the mineral and food industries, particle curtains are steadily emerging in promising new renewable energy technologies for use in concentrating solar power (CSP) plants. These solar particle receiver designs are currently in the early demonstration phase, delivering improved thermal efficiency through their direct storage of heat within sand-like particles [2, 3]. They are favoured over liquid heat exchangers due to the ability to operate at hight temperatures without having to compensate for extra pressure with enhanced infrastructure.

Currently their are two major research branches in understanding particle curtain behaviour. The first of which relates to the computational modelling of this physical phenomena whilst the alternative is through experimental investigations.

2.2.1 Computational Modelling

Currently the standard means of modelling particle curtains is divided between the Discrete Element Method (DEM), Computational Fluid Dynamics (CFD) and Single Particle Models.
In recent years it has been shown that CFD has been successfully applied to modelling particles in particle curtains

2.2.2 Experimental Investigations

2.3 Thermodynamic Principles

Within the study of thermodynamics the phenomena of heat transfer is defined as thermal energy in transit due to a spatial temperature difference[5]. There are several modes in which heat/energy transfer (Q) can be transferred from differential temperature zones. When a temperature gradient exists in a medium or between a two mediums, which may be a solid, fluid or both there are three types of energy transfer that may exist:

- Conduction - Refers to the heat transfer that will occur across or within the medium.

- Convection - Refers to the heat transfer that will occur between a surface and a moving fluid.
- Radiation - Refers to the heat transfer that will occur from any surface at a temperature greater than absolute zero.

Due to the inherently complex behaviour of matter, these three modes of energy transfer are described in very different ways although sharing the common trait to propagate toward equilibrium. A more in depth description of these modes can be seen below:

2.3.1 Conduction

Conduction may be viewed as the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles [5]. This phenomena occurs very regularly in real world scenarios with the rate of heat transfer sharing a direct proportionality between the temperature differential. Fourier's Law mathematically describes this transfer:

$$\frac{\partial q}{\partial t} = -k\left(\frac{\partial T}{\partial x}\hat{i} + \frac{\partial T}{\partial y}\hat{j} + \frac{\partial T}{\partial z}\hat{k}\right) \tag{1}$$

Where:

$\frac{\partial q}{\partial t}$	Is the thermal energy flux (W/m^2)
k	Is the thermal transport property (Thermal conductivity) $(W/m \cdot K)$
$\frac{\partial T}{\partial (x,y,z)}$	Is the temperature gradient in each the x, y and z directions respectively.

2.3.2 Convection

The convection heat transfer mode is comprised of two mechanisms. In addition to energy transfer due to random molecular motion (diffusion), energy is also transferred by the bulk, or macroscopic, motion of the fluid. This fluid motion is associated with the fact that, at any instant, large numbers of molecules are moving collectively or as aggregates.Such motion, in the presence of a temperature gradient, contributes to heat transfer[5].

This mode of heat transfer is considered as the most complex of the three due to the inherent chaotic behaviour of fluids. There are two sub categories of convective heat transfer: The first relating to natural convective behaviour where the temperature differentials between the fluid and the surface result in changes in density and thus fluid motion based on the physical properties of buoyancy. The second relates to forced convective heat transfer where there is some relative velocity difference between the bulk of the fluid and the surface of the object, in this instance the formation of a fluid velocity boundary layer occurs over the object based on the no slip condition which in turn provides the medium in which heat transfer occurs in the form of a temperature distribution within this boundary layer. In general regardless of the nature of the convection heat transfer process, the heat transfer is defined by Newton's Law of Cooling as seen in equation 2:

$$\frac{\partial q}{\partial t} = h(T_s - T_\infty) \tag{2}$$

Where:

$\frac{\partial q}{\partial t}$	Is the thermal energy flux (W/m^2)
h	Is the thermal transport property (Convective heat transfer coefficient) $(W/m^2 \cdot K)$
T_s	Is the temperature of the objects surface
T_∞	Is the bulk fluid temperature

2.3.3 Radiation & Intra-Red (IR) Theory

Thermal radiation is energy emitted by matter that is at a non-zero temperature [5]. This form of energy transfered via electromagnetic waves and unlike that of conduction or convection does not require a medium for heat transfer to occur. The rate at which energy it transmitted per unit area (W/m^2) is termed the surface emissive power. StephanBoltzmann's Law desciribes this heat transfer:

$$E = \epsilon \sigma T_s^4 \tag{3}$$

Where:

E	Is the emissive power (W/m^2)
σ	Is the StephanBoltzmann constant ($\sigma = 5.67 \times 10^{-8} W/m^2 \cdot K^4$)
T_s	Is the temperature of the objects surface
ϵ	Is the emissivity ($0 \leq \epsilon \leq 1$)

2.4 Infra-red Thermography

2.4.1 Infra-red Theory

2.5 Image Analysis/Processing

2.6 Statistical Methods currently used in Image Processing/Analysis

2.7 Camera Modelling

2.8 Model building

2.9 Conclusions

3 Methodology

References

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