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Safety Analysis of the Grain Fermentation in a Storage Silo

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ABSTRACT

The consistent rise in global grain production underscores the importance of ensuring the quality and safety of grain for consumption through effective grain storage systems. This research aims to explore the principles of thermal ignition established by Frank-Kamenetskii, in exothermic reacting systems. When an exothermic chemical reaction occurs in a storage silo, it poses the risk of a thermal explosion. An explosion ensures when the rate at which heat is generated by the chemical reaction is greater than the rate at which it is dissipated through conduction and convection across the vessel walls. Frank-Kamenetskii defined a parameter δ that shows that the explosion occurred when δ exceed a critical value depending on the geometry. This research analyzes the interplay between natural convection and thermal explosion, which enhances the understanding of the conditions leading to thermal explosions and how convection can either promote or suppress them.

Keywords: Thermal explosion, Storage silo, Natural convection, Frank-Kamenetskii parameter.

1. Introduction

The principal theory of thermal ignition developed by Frank-Kamenetskii [1], describes the exothermically reacting where heat is transferred only through conduction. Several studies have embraced this methodology [2-4] yet the incorporation of convection is crucial to avoid thermal explosion in confined containers. Jones [5]found that the critical limit to ignition δ is strongly increasing with higher Rayleigh numbers. This study focuses on the interaction between free convection and exothermic chemical reaction with the primary goal of conducting an initial investigation into the transition from the steady-state region to thermal explosion, in a cylinder container (silo) of a height H and diameter d, filled with reacting porous medium. The consumption of the reactants is insignificant; thus, the variation of the concentration can be ignored. Hence a zero-order of chemical reaction is assessed. The reacting medium is assumed to be a Newtonian fluid, where its motion is laminar and governed by Darcy's law.

2. Results and discussion

The principal aim of this investigation is to determine the dependance of the critical value of Frank-Kamenetskii number δ with the Rayleigh number in the storage silo. As the temperature within the system rises, the rate of heat production experiences a rapid increase. This can potentially trigger a self-accelerating process, where heat production accumulates within the system, leading to a potential explosion if convection and conduction fail to adequately remove the heat. Calculations indicate that the temporal evolution of the rate flow is unstable due to fluid recirculation, resulting in unbounded temperature growth. However, once this evolution reaches a constant state, the system proceeds into a stable steady-state regime. Thus, we have a criterion which allows us to divide the δ-Ra graph into two regions corresponding to explosive and steady state regime as shown in figure 01. The figure shows that δ increases with the increasing of the Rayleigh number. This behavior can be explained by that convection becomes vigorous, heat removal through the walls is improved, thus larger values of δ corresponding to higher rates of heat production can be accommodated without explosion

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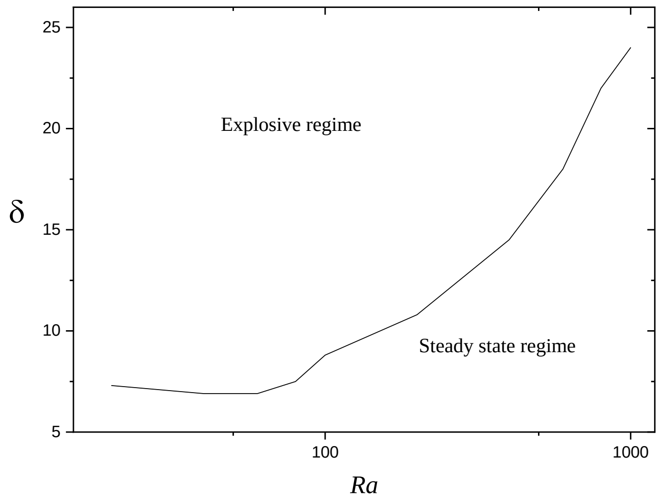

Figure 01: The evolution of the ignition critical limit δ with the Rayleigh number.

3. Conclusion

In conclusion, the examination of thermal explosions in storage silos represents a critical and evolving field of research, essential for ensuring safety in industrial and agricultural settings. The findings examined the importance of the inclusion of heat transfer by convection in order to enhance heat released throughout the walls of the vessels and thus reaching higher values of frank-kamenetskii δ without risking a thermal explosion. These insights are crucial for designing safer storage processes and implementing effective safety measures to prevent thermal explosions in such storage environments.

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