Development of an Innovative Method to Cover Grain in Open Bulkheads

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Abstract

CBH recognises the need to change their existing method of manually covering grain in open bulkheads with tarpaulins. This is a hazardous activity which CBH hope to eliminate from their open bulkheads within ten years. The objective of this project was to improve the safety and efficiency of covering grain in open bulkheads through the design of an appropriate covering material. This was achieved through an in-depth research phase into the existing tarpaulin method, concept design analysis and a formulation of the project constraints which were used throughout the design process to assess the relevance of all ideas to CBH. The use of a hard-setting spray foam cover was selected as the most promising design and two different foam compositions were tested. While the first composition did not produce a hard-setting foam, testing of the second composition is producing more promising results. Through the in-depth research and testing of the spray foam cover concept, this project has acted as a feasibility study for CBH who can use the analysis to determine if they wish to pursue the concept towards implementation.

1. Introduction

Co-operative Bulk Handling (CBH) has identified their existing method of using tarpaulins to cover grain in open bulkheads as an area which requires immediate and significant change. In 2009 CBH undertook an internal safety review which included the launch of a new safety strategy; "to result in an improved safety culture and performance within the organisation" (Co-operative Bulk Handling 2010). The objective of this project is to improve the safety and efficiency of covering grain in open bulkheads through the design of an appropriate covering material and the consideration of a mechanism to safely deploy this cover.

The motivations for the project are widespread within CBH where the covering of grain piles with tarpaulins has been identified as a safety hazard which must be removed. The 2009 safety review indicates that the business as a whole is looking to improve its practices, with the CEO Dr Andrew Crane declaring after the review that CBH "Strive to integrate safety into all aspects of our work and business" (Co-operative Bulk Handling 2010). The need for change was further highlighted in late 2010 when WorkSafe placed a prohibition order on a site in Geelong after a GrainCorp worker died whilst pulling a tarpaulin in windy conditions (Devic 2010). The GrainCorp method of covering grain in open bulkheads is similar to that of CBH and thus changes for CBH, as for GrainCorp, are mandatory. Other motivations for the project result from the limitations of tarpaulins; the tarpaulins cannot be pulled when it is raining, in strong winds or when the required number of handlers is not available. CBH has reinforced their aim to eliminate the manual tarpaulin covering method within 10 years.

CBH has invested large amounts of time and money into this design problem without success. If a suitable design is found to be feasible and is detailed sufficiently to allow for its implementation, CBH will benefit by providing a safer working environment for their employees. In fitting with the design constraints, the deployment of the cover must require fewer staff than are required at present, the operation must be straightforward and must not require significant manual handling. CBH has stressed the importance of removing staff from positions on top of the bulkheads.

1.1 Background

Open bulkheads are used throughout Australia and the world and similar manual tarping methods are used across all companies. CBH has trialled alternate methods of grain covering in their open bulkheads, though as yet none have been implemented with success.

CBH has constructed a number of mechanical devices to pull the tarps along the grain stacks. These include using sailing winches on stackers, a mobile steel frame that acts as a pulling device and a ‘moon buggy’, which climbs the grain stack and pulls the tarp along with it (Tutt, C 2011, pers. comm., 6 April). On implementation it was found that each of these methods was slower, they required more handlers and were more difficult to operate than simply pulling the tarps by hand. CBH wish to eliminate handlers from positions on top of the bulkheads and these methods failed to do that. Together these reasons for failure highlighted the need for any new design to be faster, easier to operate and less labour intensive than the manual pulling method.

While retaining the tarping method, CBH has trialled various tarpaulin materials. They have adjusted the weight, thickness and mechanical properties of the tarpaulins and have found that while the lighter tarpaulins are theoretically easier to manoeuvre, handlers in Western Australia prefer the heavier tarps as they are less susceptible to flapping and blowing in light winds (Cripps, D 2011, pers. comm., 6 April).

CBH has considered using two different covers depending on the season, with one being temporary and the other more permanent. The idea would be for a lightweight, cloth-like material to cover the grain stack in the harvest season (when deployment and retraction occur frequently) and to use a sturdier material over the winter months. Another idea discussed with CBH was the use of a polymer spray to cover the grain. This would involve a spray foam adhering to the top surface of the grain where it would set to create a hard crust. The foam would have to be impermeable and fully sealable to allow effective insect fumigation and would ideally be biodegradable, to allow for full integration with the grain. While CBH has not yet identified a suitable chemical composition, they have completed one small spray foam test. The selected spray foam did not function as desired and the idea was abandoned due to a lack of resources (Tutt, C 2011, pers. comm., 6 April).

CBH recognise the need for fast and immediate change so that manual tarping can be eliminated within ten years. By using this project to determine if the chosen final design is feasible, CBH are moving towards finding their solution. If the final design is found to be appropriate, further testing will ensue to pass the materials as food-safe and safe for operation on the grain stacks. Any design that is deemed suitable by CBH will advance the state of the art and will be relevant not only to CBH’s grain storage activities in Western Australia, but across Australia and the world.

2. Design Approach

The specific design parameters that apply to this project were analysed and a list of project constraints was formulated. The key design constraints are highlighted in Table 1 below.

Material Constraints	
100% sealable	• Effective phosphine fumigation requires that no material, solid or gas, can escape from the grain stack • Water must not be able to enter the grain stack
Resistant to phosphine	• The covering material must not be affected by prolonged exposure to phosphine gas
Food grade/food safe	• Materials to be in contact with the grain must be non-hazardous and non-toxic
Weather proof	• The material must be able to withstand harsh weather conditions and prolonged sun exposure
Bird proof	• The cover material must be strong enough to withstand repeated pecking by cockatoos
Logistics Constraints	
Cover placement	• The cover should sit directly on top of the grain; any gap between the grain the cover causes flapping and an excess volume of air requiring fumigation
Fast deployment	• Full deployment of the cover $\leq 15 mins$
Minimal staff required	• Deployment of the cover should require as few staff as possible (less than the five staff required at present)
Minimal manual handling	• High levels of manual handling must not be required of any operators or staff
Maximum 6m uncovered	• The design must allow for a maximum of 6m back from the peak of the stack to be uncovered at any one time
Staff off the bulkhead	• Staff must not be positioned on the stack at any time
Design Cost Constraints	
Implementation and operation cost	• The cost of implementing and operating the final design must be economically viable for CBH.

Table 1: Key design constraints

This list of constraints was used to understand the limitations of the existing manual tarpaulin method before it was used to determine which concept design was the most relevant to CBH. Concept designs included a steel frame over the grain stack to pull the tarpaulins and using a crane device to hold rolled tarpaulins above the stack, from where they would be released to roll down the sides of the grain stack. Both of these designs relied on the continued use of a tarpaulin-like material and would most likely still require at least one handler to be positioned on top of the grain stack; this fails to achieve the CBH wish to remove the manual tarping of the bulkheads within ten years. The focus then moved to more unorthodox ideas, including an air-supported dome structure, a partially buried stack and a spray foam cover.

The spray foam cover concept was to use sprayers positioned along the bulkhead to apply a polymer foam spray to the grain stack. The foam would adhere to the top surface of the grain where it would set to form a solid, impermeable crust. CBH had previously stressed their interest in the use of spray foam cover and this design was found to have none of the fundamental flaws, in relation to the design constraints, that had been the downfall of the designs previously investigated by CBH. The key to the success of a foam cover design was found to be producing a foam composition where the properties of the final foam would adhere to the design constraints.

The foam cover design was progressed through the design process. All design decisions were made with the consideration of the project and design constraints as well as the overall project objective; to improve the safety of covering grain in open bulkheads. The relevance of the final design to CBH will hinge on how well the design adheres to the listed constraints.

2.1 Spray Foam Research and Testing Phase 1

Research was conducted into the background mechanisms behind foam formation, foam stability and the chemicals required to produce a stable foam. Foam describes a mixture of liquid, gas and a surfactant that has been agitated to convert the mixture from a liquid to a mass of bubbles (Exerowa & Kruglyakov 1997). The strength of the foam depends on the characteristics and concentration of the surfactant, which acts to lower the surface tension of the foam film at the liquid-gas interface. The foam stability describes the capacity of the foam to maintain its parameters – bubble size, expansion ratio, total foam volume – over time (Exerowa & Kruglyakov 1997). It was found that two component foam solutions are used in the production of stable, long-lasting foam. The first solution comprises the liquid base and surfactant and the second solution incorporates a binding agent, or crosslinker. The crosslinker forms the chemical links between molecular chains which produce a three-dimensional network of connected particles. Thermosetting foams use the chemical reaction between the two component solutions as their primary means of curing.

The chemical composition of a foam deemed to be stable and biodegradable was investigated and the foam was found to be relevant to the CBH design problem. The foam, described in patent EP 0391158, is claimed to have an expansion ratio of 5 to 200 and to be biodegradable. The **A** component is a solution of sodium carboxymethyl cellulose and surfactant and the **B** solution contains aluminium acetate, to act as the crosslinker. The listed applications of the foam include seed germination and top coating for landfills; these applications are similar to grain coverage and thus the foam was put forward for testing.

Testing Phase 1 involved preparing a water solution **A** by dissolving sodium carboxymethyl cellulose and sodium lauryl sulphate in a set volume of water. A second solution **B** was prepared by dissolving solid aluminium acetate in water. The control quantities of the final foam solution are listed in Table 2. The **A** solution was shaken in a closed vessel to produce foam bubbles with the consistency of shaving cream. The **B** solution was then drizzled over the foam before the mixture was agitated further. The relative stability of the foam was determined by observing the properties of the foam soon after production and again after a delay of several hours.

Chemical	Solids content of foam solution, by weight
Sodium carboxymethyl cellulose	0.50%
Sodium lauryl sulphate	0.75%
Aluminium acetate	0.15%
Water	98.60%

Table 2: Chemical quantities used to create the control foam in *Testing Phase 1*

An indirect relationship was found between the crosslinker concentration and the degree to which the bubbles collapsed back into solution. When the final solids concentration of the aluminium acetate was increased to 2.25% (from the control value of 0.15%) there was no evidence of collapsed bubbles. While the bubbles began to set within a period of 15 minutes, when a force was applied to the set bubbles they subsided on impact. Dropping water on to the bubble surface caused the bubbles to collapse immediately and return to a gel-like solution. This indicated that the foam was open-cell and not closed-cell; closed-cell foam is required for non-permeability to be achieved. It was not possible to modify the properties of this foam further and thus the second research and testing phase began.

2.2 Testing Phase 2

Investigation into known closed-cell, water resistant foams led to cementitious foam. Cementitious foam is essentially a foamed concrete and it is composed of a cement paste with a foaming agent entrapped in air voids in the mortar (Ramamurthy, Nambiar & Ranjani 2009). Cementitious foam made with a magnesium oxide cement base is used by the American installation company Air-Krete to make closed-cell insulation. The product is an attractive insulation option as it is quick hardening, has high strength, low shrinkage, it is fire-proof, mould resistant, insect resistant, water resistant, non-toxic and the product can be recycled (Air-Krete 2009). These attributes make cementitious foam an attractive and seemingly viable option as a spray foam cover for the application of grain storage.

Testing Phase 2 incorporated testing the chemical composition of the foam used by Air-Krete and determining the properties of the hardened foam product. As with the previous phase of testing, the foam was made using two component solutions. It is the reaction of polyvinyl alcohol (in the **B** solution) with sodium metaborate (**A** solution) and the reaction of the cement compound (**A** solution) with water that causes the foam to harden.

At the time of writing the second phase of foam testing is still ongoing. Early results indicate that the foam does indeed set to form a hard crust surface. The final chemical composition to produce the required properties of a quick hardening foam, water-resistance and recyclability is yet to be finalised.

2.3 Foam Deployment

Successful application of the spray foam cover method requires the foam to be generated on-site and then for the foam to be distributed evenly across the grain stack. The methods by which the foam is applied to the stacks must adhere to the design constraints, most notably that staff members are restricted from being positioned on the grain stacks. Two possible methods of foam deployment are currently being considered. The first (Figure 1A) uses a steel frame positioned over the bulkhead to carry a series of outlet hoses from which the foam will be dispensed. Two separate foam generators are to be located at the base of each side of the frame. The second design (Figure 1B) utilises a single boom spray arm positioned behind a tractor or mounted on the back of a truck. The height and angle of the arm will be adjusted depending on the angle of repose of the grain and the height of the grain stack.

Once the composition of the final foam has been determined, the requirements of the foam will be known and these will be used to conclude which of the two designs is most feasible. The cost of the designs and the ability to use the same deployment infrastructure at multiple bulkheads will also be considered.

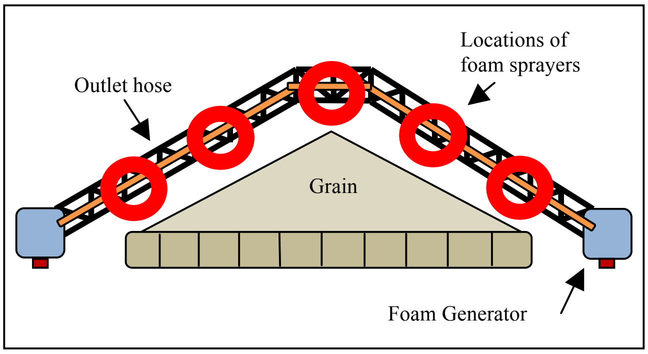

Figure 1A: Steel frame deployment design

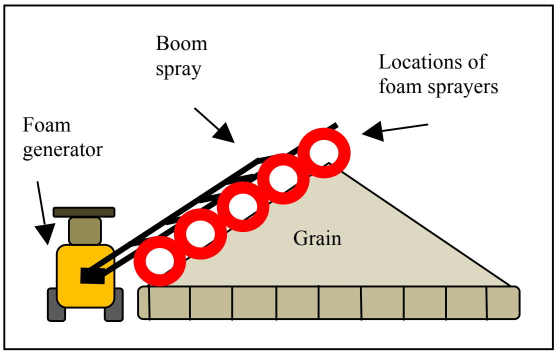

Figure 1B: Boom sprayer deployment design

3. Results and Discussion

While a final foam composition has not been determined at this stage of the project, it is envisaged that the cementitious foam currently being tested will be found suitable for the application of grain storage. If further additions to the composition must be made, such as added hardeners or catalysts, these will be added and the results compared. A final foam composition and the properties of the hardened foam will be presented to CBH on the project's conclusion.

4. Conclusions and Future Work

Early testing of a cementitious spray foam has proved that the spray foam cover concept is a feasible solution for CBH. The project objective, to determine if a new, innovative covering method is feasible, has therefore been achieved. Further testing will be conducted in the coming weeks and this should reinforce the advantages of using a spray foam cover over the existing method of manually covering grain stacks using tarpaulins.

This project has acted as an initial feasibility study for CBH and extensive testing and development of the spray foam concept will be required on the project's completion. The detailed design of the foam generator device and the method of foam generation and application will need to be conducted. Once the properties of the cured foam have been determined, the means to remove and recycle the grain can also be decided.

6. References

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