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Citation: Cheung, Wai Ming and Wallace, Kieran (2012) Design and development of an excavator mounted dust suppression system. In: ICMR 2012: Proceedings of the 10th International Conference on Manufacturing Research, 11-13 September 2012, Aston University, Birmingham, UK.

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## **DESIGN AND DEVELOPMENT OF AN EXCAVATOR MOUNTED DUST SUPPRESSION SYSTEM**

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### **ABSTRACT**

This paper reports on the investigation of an Excavator Mounted Dust Suppression System for demolition and construction activities. Ever increasing pressure is placed on contractors to improve their environmental performance especially dust emissions. Current methods of dust suppressions have been investigated and each of the methods has also been critically analysed. The investigation also looked into the requirements of such a system and a concept system proposal is produced. A working prototype has been constructed for a mini excavator complete with a hydraulic breaker. The proposed system was rigorously tested in various configurations to determine its efficiency and effectiveness in comparison with current suppression techniques. The resulting environmental and cost benefits of the system are then discussed.

Keywords: dust particles; demolition process; dust suppression system

### **1 INTRODUCTION**

Dust on construction and demolition sites has always been an issue, in particular health hazards of inhaling dust and visibility issues associated with airborne dust particles. Dust particles that cause the most significant risk to humans are particles that approximately 10 micrometers or smaller in diameter (Wu et al. 2011). As health, safety and environmental regulations are increasingly tightened, contractors and clients are forced to look into new ways of dust control. Recent Health & Safety Executive (HSE) Funded research (HSE. 2009) suggested that over 650 construction deaths from silica related lung cancer occurred in the UK in 2004. This equals to 12 construction workers a week suggesting that silica inhalation is currently the second most important cause of occupational lung cancer after asbestos.

As more and more clients and contractors introduce no dust policies, dust suppression and environmental impact become a very strong argument during National Federation of Demolition Contractors meetings. Under Part 5 of the Environmental Act 1995 and the UK Air Quality Strategy, construction site operators need to demonstrate that both nuisance dust and fine particle emissions from their sites are adequately controlled and are within acceptable limits (HSE. 2010). These limits vary between local authorities depending upon their environmental targets. The issue seems to be that the term dust suppression is open to interpretation. From a debate in America, "You need to use adequate enough water to suppress dust, although some dust will still be released just not as much as would be if done properly" (HSE. 2010). This suggests that new dust suppression technology is going to have to outperform current solutions. Therefore a new system is required to overcome these shortcomings, as such; a prototype concept is proposed. The prototype is then manufactured and tested with Tyne Tees Demolition Ltd in County Durham, UK. The layout of this paper is as follows: Section 2 highlights the theoretical background and research problem. Section 3 discusses the methodology and implementation issues. Section 5 describes a case study and data analysis finally, the conclusion and future work is presented.

## **2 THEORITICAL BACKGROUND AND RESEARCH PROBLEM**

The theory surrounding this work is simply that water suppresses dust particles; the efficiency of the suppressant is dependent upon many factors, for this investigation a Computer-Aided Engineering simulation will be used to perform stress analysis on the components. The main emphasis is focused on vibration analysis of the components and the flow analysis of the nozzles. This will reduce the need for manufacturing parts that can be tested for efficiency using Finite Element Analysis. The experiments involved in testing will be repeated to prevent inaccuracies. The results will be evaluated against current solutions and also a baseline of using no dust suppression (Gambatese and James 2001).

As a result, this research investigated the workings of a paint spray gun which delivers a variable fine spray of paint using compressed air. Paint is normally a fluid but paint guns convert paint into tiny drops-sort similar to mist. The paint could be substituted for water to produce a fine mist of water suppressant. A typical paint gun uses compressed air as low as 10 to 20 psi (pound per square inch) to atomise and propel the paint (Nicholson 2010). This means that a small compressor can be used to propel the water. As a paint gun is normally gravity fed or works on a venture a low pressure, low flow water pump may be used to reduce the size of the operating system from that of the existing excavator mounted dust suppression system. This also reduces the need for a complex nozzle, as a paint gun nozzle is very simple to manufacture and it also provides the option of an adjustable nozzle or interchangeable caps to alter the characteristics of the spray.

## **3 THE METHODOLOGY AND ITS IMPLEMENTATION**

In order to improve the existing excavator mounted dust suppression system, the proposed work will focus on the redesign of the system to suit a mini excavator. The methodology for this approach is adopted from Larman's waterfall method (Larman 2003) which takes one step at a time in a sequential manner.

### **3.1 Customer Needs**

The inspiration for this investigation propagated from a recent demolition project carried out by Tyne Tees Demolition Ltd. The project required a fifty tonne excavator with hydraulic breakers to demolish a single span concrete bridge as shown in Figure 1 (a). After the demolition process, Tyne Tees Demolition Ltd stated that a new system is needed with the following attributes:

- A dust suppression system mounted to the excavators to keep dust down.
- The system would need to be compact and durable enough to withstand the constant abuse.

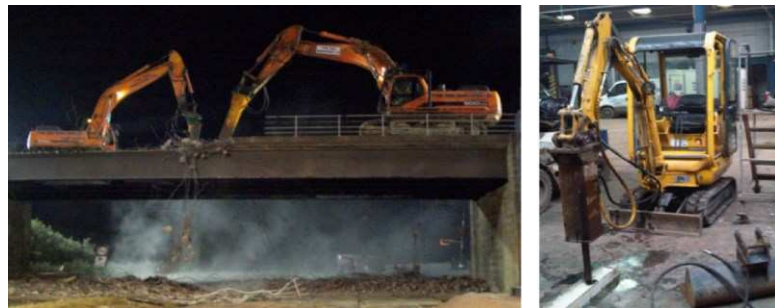


Figure 1: (a) Bridge demolition; (b) Mini excavator

#### **3.1.1 Specific Aims & Constraints**

Once the customer needs have been established, the specific aims and constraints of the system can be defined (Cheung et al., 2010). For the purpose of this investigation a mini excavator will be used for cost reasons. The specific aims of the design are: (i) dust particle release must be significantly reduced; and

(ii) the system must be compact enough to minimize the need of refilling of water used by the system The system must be durable to stand up to work in the demolition sector.

The design constraints are developed from the design aims (Bramall et al., 2003; McKay et al., 2003) and is mainly for the decision of where to mount the equipment. The mini excavator that will be used for this work is shown in Figure 1(b). There is very little space to mount a water storage device on the excavator so the device will have to be designed so that it can be mounted to the roof of the excavator.

### 3.2 Concept System Design

The design aims and constraints have defined that the proposed system must use minimal amounts of water and have the storage tank fitted to the roof of the excavator. Conventional dust control either: (i) dampens the material before it is disintegrated, thus this will minimize the release of dust particles or; (ii) uses large fans to blow water mist at airborne particles. Therefore, the proposed design must meet these two criteria so that a relatively small mist water jet will spray at the hydraulic breaker to suppress dust particles as soon as they become airborne without reducing visibility or using excess water or creating slurry. The nozzle will be designed to work in a similar way to a paint spray gun which uses the air to break the flow of the water forming a mist.

### 3.3 Concept Prototype Design

There are four main components for designing the prototype (see Figure 2): (a) the water storage tank, (b) water pump, (c) compressor and (d) nozzle. One of the requirements of the prototype is to mount the water tank on top of the roof therefore a frame will be designed to carry the water storage tank, compressor and the water pump. The nozzle can then be mounted remotely at the hydraulic breaker during the testing process. In comparison to the water storage tank, the compressor and water pump are considered as lightweight items, thus, they can be mounted at the back of the cab. All the components will be mounted in a durable frame which is suitable to carry the components and would be durable enough to withstand impacts during the demolition process.

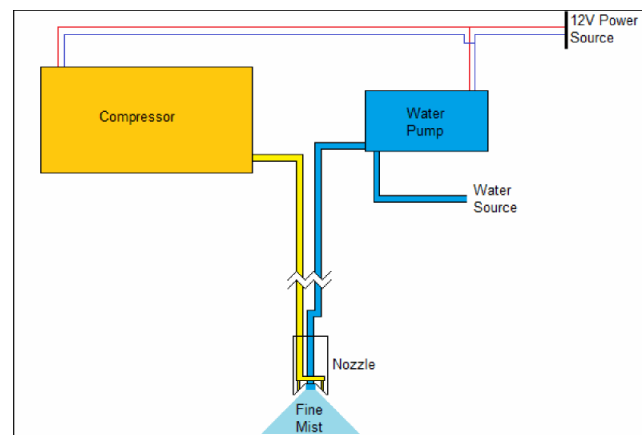


Figure 2: Concept dust suppression system

### 3.4 Final Prototype Design and Digital Model Analysis

The final design for the prototype carrier frame (a) and the components (b), (c) is shown in Figure 3. Three different nozzle designs will be analysed to determine their efficiency relative to one another. All three designs are very similar with one particular characteristic, the angle at which the air impacts the water differs for each nozzle ; The two nozzles will have air/water impact angles of 45 and 60 deg. Figure 3

(d) displays the three designs and a cross section of the 45 deg nozzle showing how the nozzles will work. The proposed final design will satisfy all of the customer needs. The design aims will comply with all of the design constraints and dust particles will be suppressed using this method. The prototype has been suitably designed to not to interfere with the excavator during the demolition process. The final design was analysed using a simulation method.

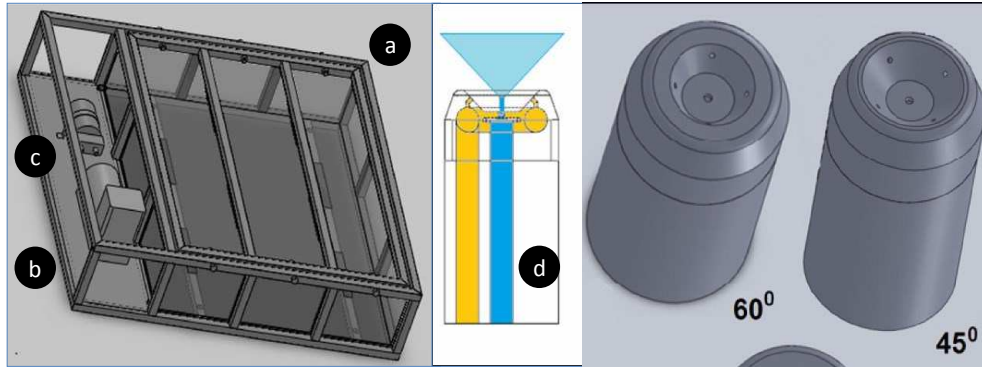


Figure 3 (i) Water tank and (ii) nozzle design

### 3.5 Prototype Manufacture

The prototype was designed so that the fitting and removal operations are simple, firstly the carrier frame and water storage tank are separated so that the carrier frame can be mounted to the excavator and then the tank lifted in and secured in place (Figures 4). Once the carrier frame and tank are fitted to the excavator, the nozzle base is mounted to the hydraulic breaker using a welded bracket. The pipes are then secured to the excavator using cable ties. The completed prototype rig was fully fitted to the excavator as displays in Figures 4 (b). For the purpose of this investigation the power supply for the prototype will be a forklift truck due to the confined battery box and low accessibility of the battery itself.



Figure 4: The Prototype System (a) fitted into a mini excavator (b)

## 4 CASE STUDY AND RESULTS

Testing was carried out using a mini excavator complete with hydraulic breaker to break pieces of concrete off the concrete blocks. The operator was instructed to produce as much dust as possible by lightly chipping at the top surface of the concrete block. The procedure is shown in Figure 5 which was used to record the results for each test. Results were recorded using the DustMate Dust monitor to determine the concentrations of “Inhalable” and “Respirable” dust particles produced during the demolition process.



Charts 1 and 2 in Figure 6 show the cumulative frequency plots for Inhalable and Respirable dust results respectively.

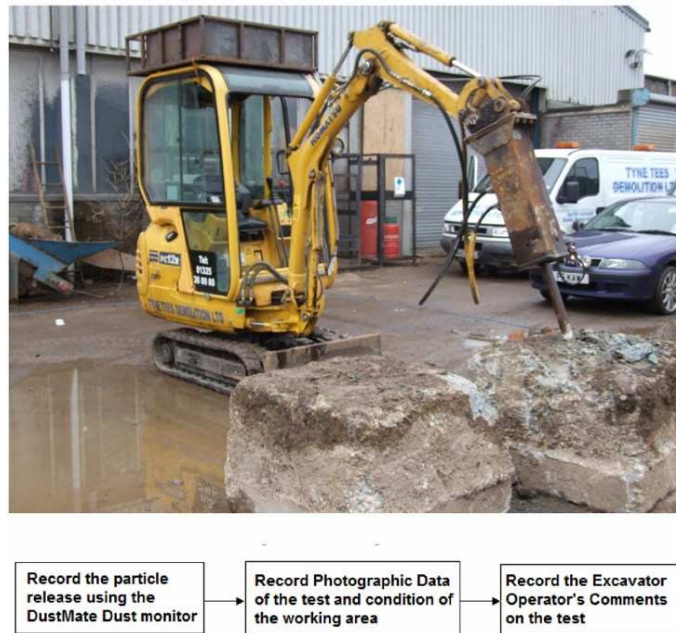


Figure 5: The testing process

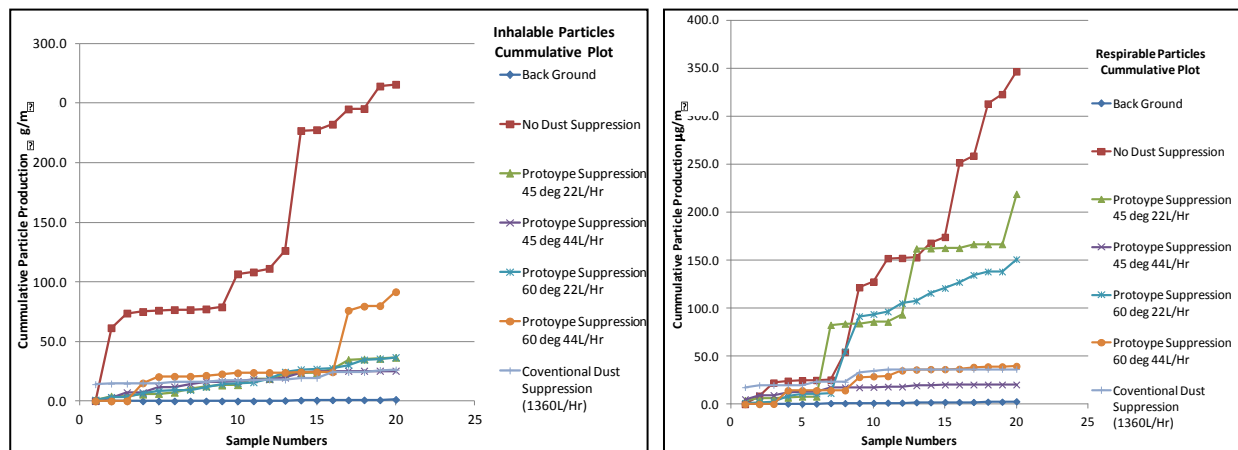


Figure 6: Chart 1 and 2 for Inhalable and Respirable dust results

The tests were carried out under suitable conditions and yielded with relevant and accurate data. The experiment has shown that the prototype is very effective in suppressing dust particles. The resulting data of both “inhalable” and “respirable” dust particles are shown in Chart 1 and 2. It is found that a 45 deg nozzle is the most effective design and most importantly it is much more effective than a conventional suppression system. This is because the prototype is working as soon as the breaker starts breaking concrete that the first particles released are suppressed almost immediately. In addition, there are fluctuations in the release of dust particles caused by dry voids, however the prototype fitted with a 45 deg nozzle can overcome these fluctuations. The difference of the 45 deg and 60 deg nozzles is evident during the two 44 l/hr flow tests. The 45 deg nozzle suppresses the sudden releases of dust far better than the 60 deg nozzle. The second determinant required from this testing is that of the water consumption and the production of slurry. During the tests, slurry was not produced by the prototype, this meant that sufficient water was

used to suppress dust but not excessively wasted. There are also environmental benefits and monetary savings due to this reduction in water usage. The approximate cost of water in the UK is 0.71p per litre, with a simple mathematical equation, it can be determined that:

- The prototype cost:  $(44\text{L} * \text{£}0.71 * 8\text{Hrs}) = \text{£}249.92$  (per 8 hour shift)
- Conventional method cost:  $(1360\text{L} * \text{£}0.71 * 8\text{Hrs}) = \text{£}7728.40$  (per 8 hour shift)

The prototype system with a 45 deg nozzle at 44 l/hr flow rate (excluding diesel costs etc) costs approximately 30 times less to run and is equally effective at reducing airborne particulate matter.

## 5 CONCLUSIONS AND FURTHER WORK

The investigation proves that the proposed prototype is effective at suppressing the dust generated during the demolition process. The findings show that the proposed prototype is effective to local dust suppression which especially beneficial than the high reach machines extensively used in demolition practices today. Further work could be carried out on the nozzles, the effectiveness of the nozzles in this investigation changed dramatically due to geometric features. Small scale bench tests could be used to find other solutions and design nozzles with higher efficiencies.

## ACKNOWLEDGMENTS

The authors would like to thank the following for assisting their research activities in this area: A5 Hydraulics, Northern Breakers Ltd and MIS Environmental for the loan of their DustMate Dust Monitor. Tyne Tees Demolition Ltd for their inspiration, guidance and the use of their facilities and equipment throughout the project.

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