Evaluation of potential on-equipment dust suppression systems for heavy construction equipment: Chain Trencher and Road Miner

Suhas Karke

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EVALUATION OF POTENTIAL ON-EQUIPMENT DUST SUPPRESSION SYSTEMS FOR HEAVY CONSTRUCTION EQUIPMENT:
CHAIN TRENCHER AND ROAD MINER

by

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Bachelor of Engineering (Civil Engineering)
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1999

A thesis submitted in partial fulfillment of the requirements for the

Master of Science Degree in Construction Management
Department of Civil and Environmental Engineering
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December 2004
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is approved in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN CONSTRUCTION MANAGEMENT

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Graduate College Faculty Representative

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ABSTRACT

Evaluation of Potential On-Equipment Dust Suppression Systems for Heavy Construction Equipment: Chain Trencher & Road Miner

by

Suhas Karke

Dr. David James, Examination Committee Chair

Professor Department of Civil and Environmental Engineering
University of Nevada, Las Vegas

The goals of this thesis research are to characterize emissions from construction equipment such as a Road Miner and Chain Trencher, develop and compare preliminary alternative designs for collection of emitted dust, and evaluate the potential economic and operational benefits of improved dust control technology.

Data collected from two site visits using PM-10 DUSTTRAK® monitors, video camera, digital photo camera, and soil samples; served as a data source to analyze construction operations, delineate sources of emissions, and characterize emissions.

Preliminary designs using vacuum and water spray dust control systems were developed for a Trencor Road Miner and a Trencor Chain Trencher. Costs for each vacuum and water spray system were evaluated and compared to find the best suitable alternative for both equipments.
A water spray system proved more feasible for a Chain Trencher and a Vacuum system is recommended for a Road Miner for dust control.

This thesis demonstrates strong potential for construction industry to improve productivity and reduce wait times, while complying with local regional and national air quality standards.
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CHAPTER 1

INTRODUCTION

1.1 Background

The control of airborne dust is an issue of concern during dry summer months in many regions of the United States, and for much of the year in arid regions of Midwest and Southwest. The Environmental Protection Agency (EPA) maintains standards for air quality that include maximum ambient levels of particulate matter with an aerodynamic diameter less than ten microns (PM-10) (Gambatese & James, 2001). The aerodynamic diameter of a particle is the diameter of a sphere with unit density (density of water) that settles in still air at the same rate as the particle in question (Friedlander, 1977).

In Southwest, non-attainment of particulate air quality standards is often caused by common sources of fugitive dust, like unpaved roads, agricultural tilling, aggregate storage piles, and heavy construction (USEPA, AP-42, 1995).

1.2 Problem Statement and Significance

The EPA has classified Clark County as a serious non-attainment area for particulate matter (USEPA, Green book, 2002). In Clark County, most of the PM-10 is of geologic origin, its sources being construction, windblown dust from
Vacant lands, emissions from unpaved roads and re-suspension from paved roads (Clark County, 1998).

Construction is one of the largest contributors, and significant atmospheric dust can be emitted during mechanical disturbance of soil. The construction industry utilizes earthmoving equipment for virtually all types of projects, including construction of roadways, bridges, residential and commercial buildings, power plants, water and wastewater treatment facilities, and other public works essential to our quality of life.

Heavy construction is a source of dust emissions that may have substantial temporary impact on the local air quality. Emissions during construction of a building or a road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a facility itself. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and prevailing meteorological conditions (USEPA, AP-42, 1995).

The types of earthmoving equipment used in construction projects include the following:

- Excavating equipment (excavators, front shovels, and backhoes).
- Loading and hauling equipment (loaders and trucks).
- Earthmovers (scrapers, bulldozers, and graders).

Other equipment is also used for moving, transferring, crushing, separating, and compacting rock and soil. The operation of each piece of equipment creates
dust that adds to the particulate emission problems from construction sites (Kothari & Gerstle, 1980).

Controlling dust on construction sites typically involves spraying water on haul roads, material stockpiles, and other areas being worked by construction equipment. Spray nozzles or manually-directed hoses attached to water trucks are used to both moisten soil to reduce the amount of emitted dust, and to knock down the dust that has already been emitted.

Both nozzle-based and hose-based spray methods include labor, operating, safety costs and scheduling complications that can limit productivity by reducing the work rate or increasing the fraction of time that a machine is idle. Alternate methods are needed that provide effective dust control while increasing productivity.

It is the purpose of this thesis to evaluate the technical and economic potential for on-equipment dust control methods to control dust emitted during soil excavation. Chain Trenchers and Road Miners have been selected as candidates for improved PM-10 controls in this thesis. Water spray (Chain Trencher and Road Miner) and vacuum-cyclone technologies (Road Miner) are evaluated.

1.3 Work Scope
The purpose of this thesis is to:

a) Characterize emissions from Chain Trenchers and Road Miners.
b) Develop preliminary designs for dust control system for collection of emitted dust from a Road Miner and a Chain Trencher.

c) Evaluate the potential economic and operational benefits of improved dust control technology.

1.4 Possible Outcome

In order to be implemented by the construction industry, new methods must be cost-effective, easy to implement, functionally viable, and safe. Several preliminary designs and cost comparisons have been completed in this thesis that generates a feasible prototype for dust control on the selected equipment.

A working hypothesis is that a successful on-equipment dust control system is expected to only reliably control dust emissions on Chain Trencher and Road Miner at minimum cost, but also reduce any possible inconvenience to the operator. An expected reduction in equipment idle times will increase overall productivity and reduce operating cost per unit production.

As a result of their high potential for creating dust, the Chain Trencher and Road Miner are selected as the ideal candidates for implementing a dust suppression system.
References

APA style of formatting has been used throughout this thesis in addition to the graduate college guidelines


CHAPTER 2

LITERATURE REVIEW

2.1 Particulate Matter

Section 2.1.1 through 2.1.3 introduces the terminology, facts, concerns and effects of particulate matter.

2.1.1 Particulate Matter Facts and Concerns

"Particulate matter" is the term used for a mixture of very-small-diameter solid particles found in the air. Major sources of airborne particulate matter are windblown dust, grinding and excavating operations, combustion by power plants and mobile sources, including diesel buses and trucks (Cooper and Alley, 2002).

"PM-10" refers to particulate matter with an aerodynamic diameter less than 10 microns in diameter.

- PM-10 particles are so small that several thousand of them could fit into the 2-millimeter diameter period at the end of this sentence.
- They are of health concern because they easily reach the deepest recesses of the lungs (EPA Fact sheet, 1997).
- Batteries of scientific studies have linked particulate matter, especially fine particles (alone or in combination with other air pollutants), with a series of significant health problems, including:
• Premature death;
• Respiratory related hospital admissions and emergency room visits;
• Aggravated asthma;
• Acute respiratory symptoms, including aggravated coughing and difficult or painful breathing;
• Chronic bronchitis;
• Decreased lung function that can be experienced as shortness of breath; and
• Work and school absences.

(EPA Fact Sheet, 1997).

2.1.2 Risk from Exposure to Fine Particles

Inhaling elevated concentrations of fine particulate matter has been attributed to increased hospital admissions, emergency room visits and premature death among sensitive populations.

• The Elderly:

Studies estimate that thousands of elderly people likely die prematurely each year from exposure to elevated ambient levels of fine particles. Studies also indicate that exposure to fine particles is associated with thousands of hospital admissions each year. Many of these hospital admissions are elderly people suffering from lung or heart disease (EPA Fact Sheet, 1997).

• Individuals with Pre-existing Heart or Lung Disease:

• Breathing elevated concentrations fine particles can harm individuals with heart disease, emphysema, and chronic bronchitis by increasing
the irritation to lungs, decreasing lung capacity, and reducing oxygenation of the bloodstream.

- **Children:** The average adult breathes 13,000 liters of air per day; or 186 L/day per kg of bodyweight. Children breathe 50 percent more air per kilogram of body weight than adults. Because children's respiratory systems are still developing, they are also more susceptible to environmental threats than healthy adults (EPA Fact Sheet, 1997).

Exposure to elevated concentrations fine particles is associated with increased frequency of childhood illnesses, which are of concern both in the short run and for the future development of healthy lungs in affected children.

Fine particles are also associated with increased respiratory distress symptoms and reduced lung function in children, including symptoms such as aggravated coughing and difficulty or pain in breathing. These can result in school absences and limitations in normal childhood activities (EPA Fact Sheet, 1997).

- **Asthmatics and Asthmatic Children**

More and more people are being diagnosed with asthma every year. Fourteen Americans die every day from asthma, a rate three times greater than what it was 20 years ago. Children make up 25 percent of the population, but comprise 40 percent of all asthma cases. Breathing fine particles, alone or in combination with other pollutants, can aggravate asthma, causing greater use of medication and resulting in more hospital visits (EPA Fact Sheet, 1997).
2.1.3 Effects on the Environment

The same fine particles linked to serious health effects are also a major cause of visibility impairment in many parts of the U.S. In many areas of the U.S. the visual range has been reduced 70% from natural conditions. For example, in the east, the current visual range is only 14-24 miles vs. a natural visibility of 90 miles. In the west, the current range is 33-90 miles vs. a natural visibility of 140 miles. Fine primary particulates (combustion and geologic) contribute a portion of this degradation in the visible range. The other anthropogenic portions come from haze aerosols produced by secondary gas to particle conversion and from direct absorption by some gases, such as NO$_2$.

Fine particles can remain suspended in the air and travel long distances. For example, a puff of exhaust from a diesel truck in Los Angeles can end up over the Grand Canyon, where one-third of the haze comes from Southern California. Emissions from a Los Angeles oil refinery can form particles that in a few days will affect visibility in the Rocky Mountain National Park. Twenty percent of the problem on dirtiest days in that Park is attributed to Los Angeles-generated smog (EPA Fact Sheet, 1997).

2.2 Fugitive Dust Sources

Fugitive dust largely arises from the mechanical disturbance of granular material exposed to the air. Dust generated from open sources is termed "fugitive", because it is not discharged into the atmosphere in a confined flow stream. Common sources of fugitive dust include unpaved roads, agricultural
tilling operations, aggregate storage piles, heavy construction, rock crushing and 
processing operations.

“Fugitive” dust is generated by two basic physical phenomena:

1. Pulverization and abrasion of the surface materials by application of 
   mechanical force through implements (wheels, blades, etc).

2. Entrainment of the dust particles by the action of turbulent air currents,
   such as wind erosion of an exposed surface by wind speeds usually over 
   19 kilometers per hour (12 miles per hour) (AP-42 USEPA, 1995).

2.2.1 Impact of Fugitive Dust

The impact of a fugitive dust source on air pollution depends on the 
quantity and drift potential of the dust particles injected into the atmosphere. In 
addition to large dust particles that settle near the source (often creating a local 
nuisance problem), considerable amounts of fine particles are also emitted and 
dispersed over much greater distances from the source.

The potential drift distance of particles is governed by the initial injection 
height of the particle, the terminal settling velocity of the particle, and the degree 
of atmospheric turbulence.

Theoretical drift distance, as a function of particle diameter and mean wind 
speed, has been computed for fugitive dust emissions. Results indicate that, for a 
typical mean wind speed of 16 km/hr (10 mph), particles larger than about 100 
microns (μm) are likely to settle out within 6 to 9 meters (20 to 30 feet) from the 
point of emission. Particles that are 30 to 100 μm in diameter are likely to 
undergo impeded settling (EPA Fact Sheet, 1997). These particles, depending
upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the source. Smaller particles, particularly PM-10 and PM-2.5, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence. As a result they can travel long distances before settling out.

2.3 Current Dust Control Measures and Viable Alternatives

Controlling dust on construction sites typically involves spraying water on haul roads, material stockpiles, and other areas being worked by the construction equipment. Truck mounted nozzles or manually-directed hoses attached to water trucks are used to pre-moisten soil to reduce the amount of emitted dust and to knock down the dust during excavation operations.

Other methods are needed that provide direct and effective dust control. To promote their implementation and use by the construction industry, new methods must also be cost-effective, easy to implement, functionally viable, safe and easy to maintain.

2.4 Water Spray System

One type of alternative dust suppression system is a water spray system attached directly to the equipment in use. Such a spray system works integrally with equipment operations to provide suppression directly at the source of dust emissions. Utilizing this type of dust suppression system on each piece of
equipment on a construction project can minimize or even eliminate the need for manual spraying from hoses or from water supply trucks.

Spray systems can be developed for different types of mining and construction equipment used, such as trucks, scrapers, loaders, and excavators.

Water sprays have been used in the past in the mining industry to capture and reduce respirable coal dust. Spray nozzles mounted within tubes were commonly used in coal mines for the purpose of diluting explosive gases released in the vicinity of coal mining machines. (Browning and Evans (1975))

Devices were developed to draw dust-laden air out of the cutting zone using water sprays mounted on the mining machines. Jones and James (1987) tested a high-pressure water spray system with in a tube to induce airflow through the tubes and capture fine dust contained in that air. As an example of practical performance, Jones and James used a 15 cm diameter tube with a spray flow rate of 0.225 litres/sec. This gave an induced airflow of 0.35 m$^3$/sec, achieved 90% capture efficiency for respirable coal dust

In field studies, Matta (1976) found that sprays mounted under the boom, on the face of mining machines reduced dust in the face returns by at least 33% (at 90 % confidence level) as compared to those mounted on the top of the boom.

In another mining application, Courtney, Jayaraman, and Behum (1978) showed that the bottom sprays were more effective when the machine was shearing down and were 50 % more effective than top sprays.

Gambatese and James, (2001) developed a prototype water spray system to be attached to a dump truck for suppression of PM-10 emissions during transfer
of material. Amongst the three systems tested, Gambatese and James (2001) found that a low pressure, low flow spray system, using cone shaped spray nozzles, operating at 2.8 kg/cm² (40psi), consuming 3.0 –2.5 gallons per minute was an efficient system in reducing PM-10 emissions.

Three nozzles, 120° spray angle, were placed 1.2 m (4 ft) spacing along each side of the truck body. The percentage reduction in aerosol measured by monitors was 32.43% at 2.81 kg/cm² of system pressure. A wind speed of over 25 miles per hour wind speed greatly decreased effectiveness of the system because of swaying of water droplets away from target area (Gambatese and James, 2001).

The typical components for a water spray system include: spray nozzles mounted on a network of tubing or pipe, which is connected to an onboard pump and a tank to supply the water.

2.5 Cyclones (Using Vacuum Technology)

The cyclone separator has long been established as a low-cost unit operation for the removal of dust particles from dusty gas streams.

Cyclones are widely used for separation and recovery of industrial dusts from air or process gasses. In synthetic detergent production, fast reactor cyclones are used in separating a cracking catalyst from vaporized reaction products (Coker, 1993).

Cyclones are used for classification as for example, in the de-gritting of kaolin clay where sand is removed from the crude clay suspension before finer
classification in a conveyor discharge centrifuge and final product recovery in a disk centrifuge (Coker 1993).

The ease of maintenance, simplicity of construction, compactness, and versatility are some of the advantages of cyclone separators compared to filters, scrubbers, and settlers. Zwicke and Shaw, (1997) found that a properly designed cyclone system can achieve efficiencies greater than 98%.

2.6 Application to this Project

Both water spray and vacuum-cyclone technologies will be considered as potential equipment controls in this thesis. Before attempting to design a control system, it is necessary to characterize the magnitudes and locations of emissions on several types of construction equipment, and also understand some of the basic properties of the locally generated dust, especially PM-10 and PM-2.5. This subject will be covered in Chapter 3.
References


CHAPTER 3

CANDIDATE EQUIPMENT, DATA COLLECTION AND FIELD OBSERVATIONS

3.1 Field Visits

Two field visits were made to several sites where construction operations were observed and recorded. Soil samples were collected and returned to the laboratory for analysis. Airborne dust measurements were taken. Videotapes of operations were analyzed. Estimated costs of equipment and operations are discussed later in the chapter.

The purpose of this chapter is to describe the methodology adopted to study emissions by the selected equipment in detail.

3.2 Candidates

The following discussion describes types and advantages of excavation equipments, namely, Chain Trencher and Road Miner.

3.2.1 Trenching Machines

3.2.1.1 Description of Trenching Machines

Trenching machines are used to dig trenches for utility lines. They have proven to be economical in continuous excavation operations, such as pipeline
Vermeer and Trencor are two major manufacturers of Chain Trenchers.

Figure 3.1 shows a Vermeer Chain Trencher model T755 accompanied by a 2000-gallon water truck.

Figure 3.1

Vermeer Chain Trencher Model T755 with a 2000 Gallon water truck (Photo by author taken at Blue Diamond Road, Las Vegas Nevada, Date November 8 2003).

There are thirteen different models manufactured by Vermeer designed to satisfy different needs. Table 3.1 gives different classification of Vermeer
Trenchers. Vermeer Trenchers can excavate trenches that are from 6" to 42" wide and 0' to 18' deep.

Table 3.1

Vermeer Trencher Classification

<table>
<thead>
<tr>
<th>Model</th>
<th>Weight</th>
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<th>Depth of Cut</th>
<th>Width of Cut</th>
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<td>Lbs</td>
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<td>0-3.66</td>
<td>0 – 12</td>
</tr>
<tr>
<td>T1255</td>
<td>82554</td>
<td>182,000</td>
<td>0-5.49</td>
<td>0 – 18</td>
</tr>
</tbody>
</table>


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Similar to Vermeer, Trencor Chain Trenchers are also classified into eleven different models given in Table 3.2. These different models are used for different applications.

Table 3.2

Different Chain Trencher models manufactured by Trencor

<table>
<thead>
<tr>
<th>Model Number</th>
<th>Operating Weight</th>
<th>Max Engine Output</th>
<th>Max Cutting Depth</th>
<th>Cutting Width Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kgs</td>
<td>Lbs</td>
<td>HP</td>
<td>Meter</td>
</tr>
<tr>
<td>660C-SS</td>
<td>27,216</td>
<td>60,000</td>
<td>260</td>
<td>1.83</td>
</tr>
<tr>
<td>860C-SS</td>
<td>38,555</td>
<td>85,000</td>
<td>350</td>
<td>2.44</td>
</tr>
<tr>
<td>665HD</td>
<td>17,237</td>
<td>38,000</td>
<td>185</td>
<td>2.44</td>
</tr>
<tr>
<td>760HD</td>
<td>22,680</td>
<td>50,000</td>
<td>210</td>
<td>2.44</td>
</tr>
<tr>
<td>765HD</td>
<td>24,948</td>
<td>55,000</td>
<td>250</td>
<td>2.44</td>
</tr>
<tr>
<td>960HD</td>
<td>38,555</td>
<td>85,000</td>
<td>325</td>
<td>3.05</td>
</tr>
<tr>
<td>1260HD</td>
<td>56,699</td>
<td>125,000</td>
<td>402</td>
<td>3.66</td>
</tr>
<tr>
<td>1460HD</td>
<td>83,915</td>
<td>185,000</td>
<td>600</td>
<td>4.88</td>
</tr>
<tr>
<td>1660HD</td>
<td>113,398</td>
<td>250,000</td>
<td>750</td>
<td>6.10</td>
</tr>
<tr>
<td>1760HD</td>
<td>170,097</td>
<td>375,000</td>
<td>900</td>
<td>6.10</td>
</tr>
<tr>
<td>1860HD</td>
<td>204,117</td>
<td>450,000</td>
<td>1500</td>
<td>10.67</td>
</tr>
</tbody>
</table>

(Retrieved and adapted on November 22 2003 from www.trencor.com/Products/chain2.htm).
3.2.1.2 Chain Trenchers

The Chain Trencher shown in Figure 3.2 is designed to simultaneously cut, excavate and manage excavated earth.

Large Trenchers can be used to create trenches in most types of earth, including dirt, clay, shale, caliche and most solid rock.

Excavation by Chain Trenchers is carried out by lowering the boom into the ground. The chain, mounted with tungsten carbide bit moves in forward direction cutting the soil. The Trencher moves in the opposite direction (backwards) as the trench is dug (Retrieved and adapted on October 20 2003 from www.trencor.com/literature/trencor_full.pdf).

The soil that is cut is raised by the Trencher chain and transferred to a cross conveyor (transverse conveyor). A transverse conveyor deposits the soil alongside the trench being excavated.
Figure 3.2

Vermeer Chain Trencher at work (Photo by author taken at Blue Diamond Road, Las Vegas Nevada, Date November 8 2003).

The chain mounted with tungsten carbide tips can be set in different patterns for optimal trenching productivity in hard material. These chains can vary in width from four inches to 96 inches with a cutting depth of as much as 35 feet (Retrieved and adapted on October 20 2003 from www.trencor.com/literature/trencor_full.pdf ).
Figure 3.3

Vermeer Chain Trencher showing cutting head (Photo by author taken at Blue Diamond Road, Las Vegas Nevada, Date November 8 2003).

Figure 3.3 shows details of the cutting head.

3.2.1.3 Advantages of Chain Trenchers

- Trenches made with this method are more stable, uniform and feature better grading compared to those cut by draglines or backhoes.
- Vertical walls obtained; at a controlled grade contribute to less finishing and less removal of material.
- The Trenchers grind soil into a fine state, which makes good backfill. The soil can be placed on either side of the trench as required.
- The process allows faster opening and closing of trenches.
• Large Trenchers use a combination of high horsepower that creates the force needed to excavate the trench and weight keeps the Trencher stable and on course to achieve superior trenching performance.

• Low cost of production per foot due to the speed of excavation and lower labor requirements.


3.2.2 Road Miner

3.2.2.1 Description

The Trencor Road Miner was developed to excavate new streets and roads to final grade in areas predominately under-laid with rock. The Road Miner (Figure 3.4) is similar to Chain Trencher has additional drums installed on either side of the cutting chain, to increase the width of the cut.

Road Miners can excavate up to a 19 foot wide travel lane to grade in a single pass. The cutting drum of the Road Miner rotates in the forward direction cutting the soil in contact.
The Trencher Road Miner is manufactured in three different models as shown in Table 3.3.
Table 3.3

Different models of Road Miner

<table>
<thead>
<tr>
<th>Model Number</th>
<th>Operating Weight</th>
<th>Max Engine Output</th>
<th>Max Cutting Depth</th>
<th>Max Cutting Width</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kgs</td>
<td>Lbs</td>
<td>HP</td>
<td>Meter</td>
</tr>
<tr>
<td>1260HD</td>
<td>56699</td>
<td>125,000</td>
<td>402</td>
<td>0.91</td>
</tr>
<tr>
<td>1460HD</td>
<td>83915</td>
<td>185,000</td>
<td>600</td>
<td>1.22</td>
</tr>
<tr>
<td>1660HD</td>
<td>113398</td>
<td>250,000</td>
<td>750</td>
<td>1.52</td>
</tr>
</tbody>
</table>

(Retrieved and adapted on October 2 2002 from www.trencor.com/literature/trencor_full.pdf)

The Road Miner is advantageous over other methods for the following reasons:

- Conventional planers or profilers are limited in their depth of cut to 8 to 15 inches per pass whereas the Road Miner can excavate up to a maximum 5 foot depth, 19 foot wide in a single pass, eliminating multiple cuts to obtain grade.

- Ripping with ripper attachment results in large boulders that must be hauled away. Voids, frequently left, have to be filled in and compacted, thus requiring a great deal of finished grade work. (Retrieved and adapted on October 2 2002 from www.trencor.com/literature/trencor_full.pdf).
Figure 3.5

Relevant dimensions of the Road Miner (Figure drawn and annotated by the author).

Figure 3.5 identifies the relevant dimensions listed in Table 3.4 for different models of Road Miner.
Table 3.4

Relevant dimensions for different models of Road Miner

<table>
<thead>
<tr>
<th>Road Miner Model #</th>
<th>1260HD</th>
<th>1460HD</th>
<th>1660HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Meter</td>
<td>Feet</td>
<td>Meter</td>
</tr>
<tr>
<td>A Max Cut Width</td>
<td>3.2</td>
<td>10.5</td>
<td>3.8</td>
</tr>
<tr>
<td>B Max Cut Depth</td>
<td>0.91</td>
<td>3</td>
<td>1.2</td>
</tr>
<tr>
<td>C Overall Length</td>
<td>8.7</td>
<td>28.5</td>
<td>11.1</td>
</tr>
<tr>
<td>D Overall Width</td>
<td>3.2</td>
<td>10.5</td>
<td>3.8</td>
</tr>
<tr>
<td>E Overall Height</td>
<td>3.2</td>
<td>10.5</td>
<td>3.7</td>
</tr>
</tbody>
</table>

3.2.2.2 Sources of Emission for Road Miner

Three zones of emissions were documented for the Road Miner during a site visit in September 2002. Figure 3.6 shows the location of these zones of emission.

1. Cutting head:

The cutting head shown in Figure 3.7 is made up of a main conveyor (similar to that in a Trencher) mounted with two cutting drums on either side. Both the conveyor and the cutting drum are mounted with tungsten carbide tips, which excavate soil.
The cutting face, directly in contact with soil, mills the native soil (mostly hard rock) into small particles. Figure 3.10 shows stills from a video made during cutting operation. Very high opacity of dust was emitted off the cutting drum be seen in the photos during an excavation operation while water was applied from a spray truck.
Figure 3.6

Sources of dust emission from a Road Miner (Figure drawn and annotated by the author).
2. Three openings at the top of central conveyor belt (shroud) (near the operator's cabin).

The central chain conveyor conveys excavated soil from the cutting head to a transverse conveyor. Figure 3.8 shows three openings in the conveyor shroud directly above this transfer point. The video recording taken during the site visits showed a dust plume rising from the three openings.
Figure 3.8

Three openings above the transfer point (Top view)

(Photo by author taken at Sunrise Colony Sienna, Las Vegas Nevada, Date September 10 2002).

3. Transverse conveyor. Figure 3.9 shows the transverse conveyor that can be positioned to dump the soil either towards the left or to the right of the machine, using a control switch in the operator’s cabin.
Figure 3.9
Transverse conveyor (Photo by author taken at Blue Diamond Road, Las Vegas Nevada, Date November 8 2003).

Figure 3.10 shows four views of excavation operations taken during two site visits. Figure 3.10 A shows Road Miner excavating for a side walk for a golf cart driveway taken at Sunrise colony Sienna, Nevada.

It is notable to see that even with dust control measures as water hose or water truck a high degree of opacity can be seen. Bottom right figure shows a cloud of dust rising because of excavation operation. Note the white blur seen on either side of the Road Miner, showing the dust emitted during excavation operation.
Figure 3.10

Video stills showing opacity due to dust emissions from the Road Miner and Chain Trencher during excavation. (Photo by author taken at Sunrise colony Sienna Las Vegas Nevada, Date November 8 2002).

Figure 3.10 B shows the opacity from the right hand side of Road Miner when excavation the sub grade for a road. Figure 3.10 C shows the opacity seen right in front of the cutting drum. Figure 3.10 D shows the opacity due to dust emissions from transverse conveyor (seen in back ground) blown by wind to the rear of equipment.
emission by seen in the back ground of a Chain Trencher. Wind blowing from the front of the Chain Trencher pushed the dust plume towards the back of the Chain Trencher.

Site visits made played an important role in data collection phase.

3.3 Characteristics of Sampled Sites

Field visits were made to two different sites to:

1. Study operational characteristics of excavating equipment.
2. Delineate sources of dust from the equipment.
3. Characterize PM-10 concentrations emissions from the Road Miner and the Trencher.
4. Measure clearances and working requirements to add onto a dust control system.

3.3.1 Site Locations

3.3.1.1 Site 1

The first site visited was a golf course development located at Sunrise Colony, Sienna, Summerlin, off Tropicana Avenue and Interstate 215 in November 2002. Grading and landscaping on the west side of the excavation was already completed.

A Trenchor Road Miner operated by H.L. Chapman Inc. (model 1660 HD) accompanied by a 2000-gallon water truck was used to excavate sidewalk for golf carts.

A 2000-gallon water truck of the type used at the two field sites was fitted with
side mounted spray nozzles as shown in Figure 3.11. In addition Figure 3.11 shows a nozzle attachment used to connect a hosepipe located behind the driver's cabin.

Figure 3.11
Water Truck Spray nozzles (Photo by author taken at Blue Diamond road, Las Vegas Nevada, Date November 8 2003).

Two additional spray nozzles mounted on a manifold in front fender, and two mounted on a manifold at the rear are shown in Figure 3.12 are usually used to spray water on unpaved road or graded site.
Figure 3.12
Water truck spray nozzles (Photo by author taken at Blue Diamond Road, Las Vegas Nevada, Date November 8 2003).

In the field the Road Miner and water were seen aligned in two different ways:

- Figure 3.13 shows Water truck aligned parallel with respect to the Road Miner.
- Figure 3.16 shows Water truck aligned angles with respect to the Road Miner.
Figure 3.13 and Figure 3.14 shows that the water truck operator has better control of emissions from the cutting head by orienting the truck parallel to the cutting head; however, he has no control on the dust emissions coming from the transverse conveyor dumping soil onto the ground.
Figure 3.14

Plan view of water truck aligned parallel to the Road Miner

Water truck

Water spray

Road Miner

Transverse conveyor dumping soil on the ground

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Figure 3.15 and Figure 3.16 show the water truck is positioned angled at the rear of the Road Miner, the truck operator can shoot water spray on both the transverse conveyor and some part of the cutting drum, but now he cannot control emissions from the front of cutting head.
3.3.1.2 Field Observations of Site 1

- Even with the best orientation of water truck relative to the Road Miner, it was observed that the spray from one water truck would control only one source at a time, either the cutting head or the transverse conveyor.

- When spraying the cutting head, the water truck could only spray down one side of the cutting head at a time, leaving the other end dry that might cause a dust plume.

- The Clark County Best Management Practices, for dust control permits, demand any excavating equipment cannot be operated unless proper dust control measures are taken (Retrieved and adapted August 12 2002 from...
Hence, in the event of a water truck leaving the jobsite to refill water, the excavating equipment has to stop work. The refill time may vary from site to site anywhere from 5 minutes to 45 minutes.

At the Sienna site, on an average the water truck had to spend 30 minutes for a refill after every hour.

The economic analysis presented in Chapter 5 gives the details of the costs reduced productivity that could be associated with deploying a truck in this manner.

These long delays and short operating cycle times could be overcome by several measures, including:

1) Deploying a second water truck to improve the Road Miner's cycle time,

2) Installing a dust control system directly on the Road Miner.

Both proposed solutions will result in increased productivity. However, installing a dust control system should be less expensive, should enhance efficient performance, with an added advantage of improved dust control.

3.3.1.3 Site 2

The second site, located at Mission and Horizon Ridge, Henderson, Nevada was visited in January 2003. The site involved development of single-family residences. The site roads were rough-graded and unpaved. Visual inspection showed that the native soil was mostly composed of GP i.e. poorly graded gravel (per ASTM D2487).
At site two, Trencor Chain Trenchers, one model number 1440 HD and the other 1260 HD, each accompanied by a 2000 gallon water truck, were used to excavate the utility lines for the residential plots under construction.

Figure 3.17 gives the relative movement of a Chain Trencher and a water truck. The dark shaded lines denote excavated trench, while the faint shaded lines show the proposed trenches to be excavated. A Chain Trencher began excavation from left (North) proceeding its way to the right hand side (South) of Figure 3.17.

At this site due to access restrictions caused by spoil berms, the water truck operator had to use a handheld hose to control the dust emitted from the Trencher (Fig 3.10 D).

The solid arrow denotes the movement of water truck as the excavation began. The economic analysis presented in Chapter 5 gives the details of the costs reduced productivity that could be associated with deploying a truck in this manner.
3.4 Data Recording

Data was recorded by:

- TSI DUSTTRAK® PM-10 monitors to measure suspended particulates.
- Video and still photographic recording for construction operations.

Soil samples collected for sieve analysis.
3.4.1 Description of PM-10 Monitors

Two TSI DUSTTRAK® Model 8520 PM-10 monitors were used to take readings of aerosol emitted and to characterize emission sources, and gave insight into the productivity related issues like cutting speed of the equipment in-site soils and operation cycle time.

3.4.2 Field Deployment of DUSTTRAK® and Data analysis

At both sides one DUSTTRAK® was used about 15 feet upwind of the equipment to monitor background concentrations and the other unit was used to get aerosol concentration readings on the downwind side in the plume at a distance of about 15 to 20 feet from the equipment. The DUSTTRAK® monitors were set to read at the same time. Care was taken by the field investigators to always be in the plume in the event of change of plume orientation due to fluctuation in wind direction. Winds were light 0.5 – 1.5 m/sec and variable in direction.

The TSI’s were set to a 1 second sampling interval frequency and an average run length of 10 minutes.

On return to the lab, the PM-10 data were downloaded to a Gateway 2000 G 6 200 desktop computer using TrakPro® version 3.03 (software provided by TSI Inc. MN, USA.) Graphs of aerosol concentration (mg/m3) vs time were plotted for each run using Microsoft Excel (Microsoft Windows© 2000 Professional®). Average concentrations were calculated by summing the PM-10 data and then dividing by the total time. The difference between the background reading and
the reading obtained, from the DUSTTRAK® in the plume, gave an estimate of
the PM-10 concentration in the equipment plume.

3.5 Soil Collection Method

Samples of both the undisturbed and excavated soil were collected from
several representative locations at site 2.

The aim of performing a sieve size analysis on the soil samples was to get an
idea of the particle size distribution of soil being excavated. These soil
parameters were subsequently used in design of vacuum-based system for the
Road Miner to calculate potential efficiency of a cyclone separator.

At each site the parent material sample, consisting mostly big cobbles with
little fines was dug off from the top 40-50 cm layer. Representative soil samples
from the native (parent) material, soil thrown off the transverse conveyor and that
from the cutting face were taken from different piles, dated, tagged and sealed in
zip lock® plastic bags.

3.6 Soil Analysis Method

Collected soil samples were analyzed for grain size analysis, moisture
content. The sieve size analysis is divided into two parts

1. Sieve (Grain) Size Analysis for particles greater than 75μ.
2. Sieve (Grain) Size Analysis for particles less than 75μ.
sample at site 1 showed that native soil was mostly loose rock with a size mode of GP i.e. poorly graded gravel (per ASTM D2487).

3.7 Soil Analysis results – Site 2

Site 2 soil consisted of mostly cobbles (75mm to 300 mm) and soft rock. The size reduction of the native soil can be clearly seen from the Figures A.1, A.2 and A.3. Figure A.1 in Appendix I shows parent soil being GP (poorly graded) mostly (80%) composed of particle size from 5mm to 50 mm. Figure A.2 shows that distribution of 50% of particles being in the range of 0.5mm to 10 mm. The same trend continues with the grain size distribution in the soil sample obtained from the transverse conveyor.

3.8 PM-10 Results

PM-10 concentrations were collected from two Chain Trenchers at different times. The site, being in the grading stages showed background emissions coming from on- going construction traffic.

Table 3.5 gives the summary of average PM-10 emissions collected from the trenching operation for seven runs at site 2. Each run represented a different trenching operation.
Table 3.5
PM-10 emission summary observed for Chain Trencher (Site 2)

<table>
<thead>
<tr>
<th>Run</th>
<th>Start Time</th>
<th>Duration</th>
<th>Average Background Up Wind Concentration mg/m³ (BE)</th>
<th>Average Down Wind Concentration mg/m³ (DE)</th>
<th>Difference (DE-BE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:59:16</td>
<td>8</td>
<td>0.037</td>
<td>0.516</td>
<td>0.479</td>
</tr>
<tr>
<td>2</td>
<td>10:00:24</td>
<td>10</td>
<td>0.031</td>
<td>21.54</td>
<td>21.509</td>
</tr>
<tr>
<td>3</td>
<td>10:17:46</td>
<td>10</td>
<td>0.072</td>
<td>1.054</td>
<td>0.982</td>
</tr>
<tr>
<td>4</td>
<td>10:48:01</td>
<td>10</td>
<td>1.094</td>
<td>5.29</td>
<td>4.196</td>
</tr>
<tr>
<td>5</td>
<td>10:59:02</td>
<td>10</td>
<td>0.013</td>
<td>3.982</td>
<td>3.969</td>
</tr>
<tr>
<td>6</td>
<td>11:09:43</td>
<td>10</td>
<td>0.013</td>
<td>2.822</td>
<td>2.809</td>
</tr>
<tr>
<td>7</td>
<td>11:26:58</td>
<td>10</td>
<td>0.022</td>
<td>2.527</td>
<td>2.505</td>
</tr>
<tr>
<td></td>
<td>Total time</td>
<td>68</td>
<td>Geometric Average mg/m³</td>
<td></td>
<td>2.749</td>
</tr>
</tbody>
</table>
Table 3.6

PM-10 emission summary observed for Road Miner

<table>
<thead>
<tr>
<th>Run</th>
<th>Start Time</th>
<th>Duration</th>
<th>Average Background Up Wind Concentration $\text{mg/m}^3$ ${\text{BE}}$</th>
<th>Average Down Wind Concentration $\text{mg/m}^3$ ${\text{DE}}$</th>
<th>Difference $\text{mg/m}^3$ ${\text{DE-BE}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8:56:39</td>
<td>10</td>
<td>0.037</td>
<td>1.125</td>
<td>1.089</td>
</tr>
<tr>
<td>2</td>
<td>10:48:33</td>
<td>0:26:57</td>
<td>0.135</td>
<td>1.964</td>
<td>1.829</td>
</tr>
<tr>
<td>3</td>
<td>11:45:20</td>
<td>0:32:35</td>
<td>0.031</td>
<td>7.74</td>
<td>7.709</td>
</tr>
<tr>
<td>Total time</td>
<td>1:09:30</td>
<td>Geometric Average $\text{mg/m}^3$</td>
<td>3.542</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.18 shows a plot of PM-10 concentration measured by the DustTrak® monitors versus time observe during excavation operation by Chain Trencher at 8:59 am at site 2.
Figure 3.18

PM-10 plume concentration plot for Chain Trencher.

Solid line shown in Fig 3.18 represents down wind TSI DustTrak reading while the dashed thin line represents the background emission occurring due to construction traffic. PM-10 concentration is plotted on the Y-axis on a logarithmic scale, while X-axis shows the time of recording. The plot shows several sustained peaks in the range of 3-5 mg/m³ observed on the downwind side of the equipment.
Figure 3.19 shows a similar plot of PM-10 concentration in mg/m$^3$ versus time taken for time interval starting at 10:00:24 am. This second sample plot shows much more variation in the upwind (shown by dotted line) and downwind concentration (shown in solid line). Sustained peak values generally ranged from 10-100 mg/m$^3$. 

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Figure 3.20 gives a cumulative plot of PM-10 concentration taken for a Chain Trencher versus time. This plot gives a better visual idea of the total PM-10 concentration observed by the DustTrak monitors.

The USEPA PM-10 standard allows a maximum of 0.150 mg/m³ daily average and 0.050 mg/m³ of annual average concentration. It is clearly seen that even with adoption of a dust control measure like a water truck and allowing
for a factor of 100 downwind decrease in plume concentration, in the event that excavation operations last for the better of a day, a PM-10 plume transported down wind from a Chain Trencher excavation operation could exceed the 24 hour standard at a monitoring station nearby. There is a need to find alternative effective ways of dust control on Chain Trencher and Road Miner.
References


Clark County Website:
http://www.co.clark.nv.us/pubworks/Prof_Svcs/Provisions/pdf/637.pdf).

TRAKPRO™ Data Analysis Software, January 1995, TSI Inc. MN, USA.
Chapter 4

PRELIMINARY DESIGN

4.1 Objectives

The objective of this chapter is to describe development of preliminary on-equipment design using either vacuum technology or a water spray system to reduce dust emissions from two different types of construction excavating equipment, a Road Miner and a Chain Trencher.

This chapter develops preliminary designs that will be used to generate initial cost estimates of the two alternatives: installed and operating cost. These costs will be used to determine if there are potential economic benefits for on-equipment dust control as compared to costs and productivities of current off-equipment dust suppression systems later in Chapter Five.

An on-equipment dust suppression system would be directly attached to the equipment body (Road Miner or Chain Trencher). Variations in the equipment size associated with different model types and numbers, and shapes used in practice would require the system to be modified to match different equipment models (For example, based on a series of Chain Trenchers, one would expect to have longer hoses, larger water tanks, and more nozzles as equipment size increases).
The preliminary designs developed here pertain to the Trencor Road Miner model # 1660 HD (vacuum), and the Trencor Chain Trencher model # 1260 HD (water spray).

4.2 Components of a Vacuum-based Dust Suppression System for Road Miner

A vacuum system as envisioned involves the following components:

1. Hoods: to contain dust emission for a limited time and prevent it from being entrained and swayed away by cross winds
   
   1. Semicircular hood, half the size of cutting drums on either side of the cutting drums.
   
   2. A 4" wide rectangular hood proposed to be mounted on the existing protective.
   
   3. Shroud extending half depth of the cutting head.

Additional flexible curtains are proposed to on all four sides of the cutting head to prevent any short-circuiting of dusty air into the surroundings.

2. Blowers: Centrifugal blowers will be used to force the dusty air from the capture area into the collection hoods and from the hoods to a cyclone collection chamber via ducting. For example a centrifugal blower is proposed to be mounted on one side of the cutting drum. The end directionally opposite to the blower on the drum will be provided with a hood. The blower will force dusty air from the capture zone into the hood using the principle of an air knife head. Another centrifugal blower placed immediately above the hood will now force this dusty air into a cyclone chamber via ducting.
3. Ducting: Air velocities in the ductwork, when carrying particulates, must be designed to keep the particulates in suspension. This means that carrying velocities must be sufficiently high (4000 ft/min for medium high density particles like cement, sand blast, grinding) to prevent settling of the largest particles being conveyed (Cooper and Alley, 2002).

The largest target particle diameter of 100 micron is considered to be the cut size for particles captured in the vacuum system. Particles larger than this will not be conveyed far on the wind. Cooper and Alley (2002) adapted work of Wark and Warner (1981), stated that a terminal settling velocity of particle with density of 3 gm/cc, size of 100 microns will settle at 70 cm/sec and a particle with density of 2 gm/cc, size 100 micron will settle at velocity of 50 cm/sec. A capture velocity of 1 m/sec (>0.7 m/sec for a 100 micron particle of density 3 gm/cc) is adapted in this proposed design.

Ducting will be provided as follows:

Ducting locations are schematically shown in Figure 4.1. Starting on one side of the radial hood, the duct would follow a path half way over shroud, until it reaches the center of cutting drum, and then follow the center line of the boom to the back end of the equipment, where it will be directed into the vacuum collector.

The length of the ducting is calculated as: half of the maximum cutting edge of Road Miner, plus half diameter of the cutting drum, plus overall length of Road Miner, plus half overall height of Road Miner.

follows: “Cyclones are also referred to as cyclonic collectors, centrifugal separators, and inertial separators. Centrifugal and inertial forces, induced by forcing particulate-laden gas to change direction, remove particulate matter from the dusty air stream. High efficiency single cyclones can remove 5 μm particles at up to 90% efficiency. For PM-10 the efficiency ranges from 60 to 95 %”.

One cylindrical cyclonic collection chamber with a 50 % cut size of 10μm is proposed to collect and separate dust from the dusty airflow.

5. Fan: Fan provided at the exit of cyclonic collection chamber. The proposed system design is a hybrid push-pull system.

(a) A centrifugal blower on the side of the cutting drum, centrifugal blowers above the hoods, on the mouth of ducting provide the “push”, directing air and entrained dust into the collection system.

(b) The “pull” is provided by another fan (placed sequentially after cyclone) that will create a suction force on the dusty airflow, drawing dusty air through the ducts and through the cyclones.

Section 4.3 explains the generalized steps to be followed in design of vacuum system.
Figure 4.1

Schematic of proposed ducting (Sketch drawn by author)
4.3 Steps in Design

1. Determine the capture zone.

2. Calculate the airflow and losses associated with the dust suppression system.
   a. Calculate the airflow through the hoods.
   b. Calculate the total duct length to be provided.
   c. Sum all the total airflow to be handled including losses for
      i. Static pressure loss (SP) in hood.
      ii. Entry loss in duct.
      iii. Frictional loss in duct (hf).
      iv. Fitting pressure loss in duct.
      v. Acceleration loss in duct (Pa).
      vi. Pressure loss in cyclone.

   All these losses are discussed in detail later in Section 4.4.

   Determine the power required to push the dusty air stream from duct through the cyclone chamber.

3. Calculate the dimensions of the cyclone, pressure drop and power consumption.

4. Design centrifugal fan from fan curves.

5. Check if the required power supply is available on the equipment.

6. Check equipment for space requirements.
4.4 Design Calculations for Vacuum-based Dust Suppression System for the Road Miner Model # 1660 HD

The preliminary design calculations for vacuum dust suppression system Road Miner model # 1660 HD are given in the following discussion.

4.4.1 Determining Capture Zone, and Volumetric Air Flow Requirements

The capture zone indicates the area that will have a hood or intake directly mounted over the source of emissions to collect and convey the dusty air stream.

Site visit observations and review of video records showed that dust was emitted from two areas on the Road Miner:

- Cutting head
- Three hatch openings located directly above the transverse conveyor,

The airflow in the system includes air drawn from these capture zones that are to be shrouded by hoods.

Table 4.1 gives the airflow calculations for the proposed hood on the cutting head. In the airflow formula given in Table 4.1, capture velocity (V) should be greater than terminal settling velocity of the target particle. The largest target particle diameter of 100 micron is considered to be the cut size for particles captured in the vacuum system. Particles larger than this will not be conveyed far on the wind.
Cooper and Alley (2002) adapted work of Wark and Warner (1981), stated that a terminal settling velocity of particle with density of 3 gram/cm$^3$, size of 100 microns will settle at 0.70 m/sec and a particle with density of 2 gram/cm$^3$, size 100 micron will settle at velocity of 0.50 m/sec.

As a safety factor we have considered a capture velocity of 1.0 m/sec so that design particle size can be captured (>0.7 m/sec for a 100 micron particle of density 3 gm/cc).

Figure 4.2
Perspective Sketch of Road Miner cutting head (drum) with proposed hood on it (Sketch drawn by author)

To capture the dusty air stream rising from the front of hood, a centrifugal blower...
placed at one end of cutting head will blow the dusty air stream from one side of the cutting head to the other using an air knife head. Air knives work by directing a sheet of high velocity air over a surface to be cleaned.

Figure 4.2 shows a schematic of a centrifugal blower, directionally opposite end of the knife head, placed above the hood. This blower will collect the dusty air by suction and direct the dusty air towards the cyclone collection chamber via ducting. Hence it will be necessary to take into account the airflow to be handled by the centrifugal blower. Table 4.1 gives the calculations of airflow for side view of hood on the cutting head. The flexible curtain is proposed to be constructed from slots of 6 mm thick abrasion resistant sheeting.

Table 4.1

Airflow calculations for hood looking at the side view of cutting head.

<table>
<thead>
<tr>
<th>Airflow Calculation for Proposed hood on cutting head</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cutting head radius</td>
</tr>
<tr>
<td>2. Cutting head half area</td>
</tr>
<tr>
<td>3. Hood clearance (X)</td>
</tr>
<tr>
<td>4. Distance from center of drum</td>
</tr>
<tr>
<td>5. Hood area</td>
</tr>
<tr>
<td>6. Annular area (A)</td>
</tr>
<tr>
<td>7. Capture Velocity (V)</td>
</tr>
<tr>
<td>8. Airflow = Q = V (A + 10 X²)</td>
</tr>
</tbody>
</table>

Airflow formula retrieved August 25 2003 from

The minimum non-settling velocity in ducts required is 4000 ft/sec (Danielson, 1973).

Table 4.2

Minimum flow rate required for 6” duct.

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Duct size (6”)</td>
<td>0.2</td>
<td>m</td>
<td>0.5</td>
<td>ft</td>
</tr>
<tr>
<td>2</td>
<td>Area</td>
<td>0.02</td>
<td>ft²</td>
<td>0.19635</td>
<td>ft²</td>
</tr>
<tr>
<td>3</td>
<td>Velocity</td>
<td>1219.5</td>
<td>m/min</td>
<td>4000</td>
<td>ft/min</td>
</tr>
<tr>
<td>4</td>
<td>Minimum Flow rate required</td>
<td>0.4</td>
<td>m³/sec</td>
<td>785.39</td>
<td>CFM</td>
</tr>
</tbody>
</table>

Since the minimum flow rate to avoid settling (Line 4, Table 4.2) exceeds the minimum flow rate for capture (Line 9, Table 4.1), the larger value will be used in the system design.
Figure 4.3


Figure 4.4 shows two of the three openings directly above the junction of transverse conveyor and central cutting head conveyor.
Figure 4.4
Openings above the junction of transverse conveyor and cutting head conveyor.
(Photo by author taken at Sloan pit, 215 and Charleston, Las Vegas Nevada, Date July 5 2002).

Two equal sized openings ‘a’ on either side of a larger opening ‘b’. The main central conveyor dumps the excavated soil on to the transverse conveyor sending a plume of dust through the three openings directly above the junction. Air Flow calculations for three access hatch openings above the transverse conveyor are given in Table 4.3.
### Table 4.3
Air Flow Calculations for openings at top of transverse conveyor.

<table>
<thead>
<tr>
<th>Air Flow Calculations for Three Openings at Top of Transverse Conveyor</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Total Area (A) = Areas (2a+b)</td>
</tr>
<tr>
<td>Capture velocity (V)</td>
</tr>
<tr>
<td>Clearance (X)</td>
</tr>
<tr>
<td>Flow rate Q = V (A + 10X²)</td>
</tr>
</tbody>
</table>

All the airflow from the capture zones are summed up and displayed in Table 4.4.

### Table 4.4
Summary of airflow from capture zones.

<table>
<thead>
<tr>
<th>Capture Zone</th>
<th>Flow rate</th>
<th>Flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³/sec</td>
<td>CFM</td>
</tr>
<tr>
<td>1 Proposed hood on front cutting head</td>
<td>0.371</td>
<td>785.50</td>
</tr>
<tr>
<td>2 Openings at top of transverse conveyor</td>
<td>0.511</td>
<td>1081.92</td>
</tr>
<tr>
<td>Total Airflow for capture zone</td>
<td>0.881</td>
<td>1867.42</td>
</tr>
</tbody>
</table>

As discussed earlier in the chapter the subsequent discussion involves determining size of centrifugal blowers and various pressure losses in the
4.4.2 Centrifugal Blowers

A centrifugal blower is proposed to be placed on one side of the cutting head. Air blown by centrifugal blower through an air knife will entrain the dusty air and direct it towards the hood placed at directionally opposite end of the blower.

Cooper and Alley (2002) adopted the recommendation of Danielson (1973) for minimum conveying velocity of 73170.73 m/sec (4000 ft/min) for medium-high density particulates (cement, sandblast and grinding). Assuming that the nature of cement, sandblast and grinding operation is relatively close to the operation of Road Miner excavating soil, the minimum velocity to be maintained in ducts would be 73170.73 m/sec.

It is proposed to use a 15.24 cm (6-inch) duct for the system. Amongst available centrifugal blowers in the market, two blowers, each size 146 manufactured by New York Blower Company® provide 1,113 CFM flow rate > air flow required in lines 1 and 2, Table 4.6. These two centrifugal blowers mounted directly on the mouth of the ducting, will direct the air from capture zones into two separate parallel ducts, which, converge near the entrance of the cyclone chamber.

Since the two duct lines are parallel, the flow rates are to be added while the static pressure head remains the same. If the blowers are used in series flow rate remains the same but the static pressure head needs to be summed up.

4.4.2.1 Check for Minimum Velocity Required

Table 4.5 gives the check for minimum non-settling velocity required in a duct.
Table 4.5

Check for minimum non settling velocity required in duct.

<table>
<thead>
<tr>
<th></th>
<th>Diameter of proposed duct</th>
<th>6.00</th>
<th>Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Conversion</td>
<td>/12</td>
<td>Inches/foot</td>
</tr>
<tr>
<td>3</td>
<td>Conversion</td>
<td>/3.28</td>
<td>foot/meter</td>
</tr>
<tr>
<td>4</td>
<td>Diameter of duct</td>
<td>0.15</td>
<td>meter</td>
</tr>
<tr>
<td>5</td>
<td>Area of duct (duct 6&quot; dia ) A&lt;sub&gt;i&lt;/sub&gt;</td>
<td>0.0365</td>
<td>m&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Flow rate provided</td>
<td>1113.00</td>
<td>CFM</td>
</tr>
<tr>
<td>7</td>
<td>Conversion</td>
<td>35.29</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/ft&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>Flow rate provided at duct (Q)</td>
<td>31.54</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/min</td>
</tr>
<tr>
<td>9</td>
<td>Velocity provided in duct (Q/A&lt;sub&gt;i&lt;/sub&gt;)</td>
<td>1728.2</td>
<td>m/min</td>
</tr>
<tr>
<td>10</td>
<td>Velocity provided in duct V&lt;sub&gt;i&lt;/sub&gt;</td>
<td>5668.5</td>
<td>ft/min</td>
</tr>
<tr>
<td>11</td>
<td>Minimum velocity required</td>
<td>4000</td>
<td>ft/min</td>
</tr>
</tbody>
</table>

Max CFM = 1,113 SIZE 146 12" SP @ 4.17 BHP (shaft power)

Therefore the velocity provided in duct V<sub>i</sub> would exceed the minimum velocity required (73170.73 m/sec). A centrifugal blower of 1,113 CFM capacity will be sufficient to convey the dusty air stream into the hood without settling any dust particles in the duct.
4.4.3 Determining Losses

4.4.3.1 Acceleration Loss (VPa)

There is an acceleration loss that comes from accelerating ambient air to the duct velocity. Acceleration loss is calculated as follows:

\[ V_{Pa} = \left( \frac{V}{4005} \right)^2 \]

Adapted from Cooper and Alley (2002)

Where

\( V_{Pa} \) = velocity pressure (pressure loss due to the acceleration of still air to velocity \( V \)), in HgO.

\( V \) = air velocity in the duct, ft/min

Velocity in duct imparted by centrifugal blower =

\[ V = \frac{\text{Flow rate (Q)}}{\text{Area of Duct (A)}} \]

\[ V = \frac{1113 \text{ cfm}}{(\pi \times (6/12)^2 / 4) \text{ ft}^2} \]

\[ V = 5668.5 \text{ ft/min} \]

\[ V_{Pa} = \left( \frac{V}{4005} \right)^2 \]

\[ = \left( \frac{5668.5 \text{ ft/min}}{4005} \right)^2 = 2.0 \text{ inches of HgO.} \]

4.4.3.2 Static Pressure Loss (SP)

The static pressure loss (SP) due to turbulence created during the air entry into the hood is related to the duct air velocity pressure by a hood entry loss factor \( F_h \).

\[ \text{Static pressure loss (SP)} = F_h \times V_P \] \hspace{1cm} \text{(Cooper and Alley, 2002)}

Where

\( F_h \) = hood entry loss factor

\[ V_P = \left( \frac{V}{4005} \right)^2 \]
Where $VP = \text{Velocity Pressure, inches of } H_2O$

$V = \text{air velocity, ft/min}$

$4005 = \text{conversion factor to convert air velocity into head loss, ft/}
\text{min in water column}$

A typical hood entry loss factor is 0.9 Table 4.6 (McDermott, 1976 as cited in Cooper and Alley, 2002). Duct velocity for a 6 inch diameter duct is estimated as follows:

$$V = \frac{\text{Flow rate (Q)}}{\text{Area of Duct (A)}}$$

$$V = \frac{1113 \text{ cfm}}{\pi \times (6/12)^2 / 4} \text{ ft}^2$$

$$V = 5668.5 \text{ ft/min}$$

Static pressure loss is calculated as follows:

$$SP = 0.9 \times \left(\frac{V}{4005}\right)^2$$

$$= 0.9 \times (5668.5 \text{ ft/min} / 4005)^2 = 0.9 \times 1.415 \text{ inches of } H_2O$$

$$= 2 \text{ inches of } H_2O$$

The pressure loss due to hoods is a strong function of the hood size and the air velocity in the duct leaving the hood. Table 4.6 gives the values for hood entry loss factor $F_h$ for various shapes of hoods.
Table 4.6

Hood Type, Entry Loss Factors, and typical Static Pressure Loss.

<table>
<thead>
<tr>
<th>Hood type</th>
<th>Entry Loss Factor, $F_h$ (as a fraction of Duct Velocity Pressure $(VP)$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un flanged</td>
<td>0.9</td>
</tr>
</tbody>
</table>

(Adapted from McDermott, 1976 as cited in Cooper and Alley (2002)).

Entry loss for un-flanged hood = $0.9 \times VP$

Entry loss for un-flanged hood = $0.9 \times 2 = 1.80$ inches of $H_2O$

To compensate this entry loss and prevent the particles from settling another centrifugal blower model number 146 (manufactured by New York blower Company©) powered by mechanical direct drive will provide 1,113 CFM of airflow at 12" SP. The 146 centrifugal blower needs 4.17 BHP of shaft power supply.

4.4.3.3 Determining Duct Lengths and Duct Losses

The next step is to calculate ducting length to be provided.

Frictional losses in the ducts can be calculated by multiplying the frictional loss per foot of duct length with the total equivalent straight length of duct used. Total equivalent straight length of ducting can be calculated by summing up straight run lengths with equivalent straight runs for bend, elbows etc. Table 4.7
gives the values of equivalent lengths to be considered for various fittings.

Table 4.7
Fitting pressure loss factors and equivalent duct lengths

<table>
<thead>
<tr>
<th>Fitting</th>
<th>Equivalent duct length (as a multiplier of duct diameter)*</th>
<th>Kf *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tee 45</td>
<td>45</td>
<td>2.0</td>
</tr>
<tr>
<td>90 Elbow</td>
<td>29</td>
<td>0.9</td>
</tr>
<tr>
<td>60 Elbow</td>
<td>14</td>
<td>0.6</td>
</tr>
<tr>
<td>45 elbow</td>
<td>10</td>
<td>0.45</td>
</tr>
</tbody>
</table>

(* Adapted from Industrial Ventilation, 1972, Crawford, 1976 as cited in Cooper and Alley (2002)).
Figure 4.5

Overall dimensions of Road Miner.
Figure 4.5 gives overall dimensions A, B, C, D, E and F corresponding to the entries in Table 4.8.

Table 4.8
Calculation of ducting length for different Road Miner models.

<table>
<thead>
<tr>
<th>Road Miner Model #</th>
<th>1260HD</th>
<th>1460HD</th>
<th>1660HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description (see Figure 4.6)</td>
<td>Meters</td>
<td>Feet</td>
<td>Meters</td>
</tr>
<tr>
<td>A Max. Cut Width</td>
<td>3.2</td>
<td>10.40</td>
<td>3.8</td>
</tr>
<tr>
<td>B Max. Cut Depth</td>
<td>0.91</td>
<td>3.00</td>
<td>1.2</td>
</tr>
<tr>
<td>C Overall Length</td>
<td>8.7</td>
<td>28.40</td>
<td>11.1</td>
</tr>
<tr>
<td>D Crawler Length</td>
<td>4.6</td>
<td>14.00</td>
<td>4.6</td>
</tr>
<tr>
<td>E Overall Width</td>
<td>3.2</td>
<td>10.40</td>
<td>3.8</td>
</tr>
<tr>
<td>F Overall Height</td>
<td>3.2</td>
<td>10.48</td>
<td>3.7</td>
</tr>
<tr>
<td>G Track Width</td>
<td>2.9</td>
<td>9.40</td>
<td>3.4</td>
</tr>
<tr>
<td>Ducting length required =</td>
<td>12.4</td>
<td>40.44</td>
<td>14.44</td>
</tr>
</tbody>
</table>


The total length of duct as per Table 4.8 is given by

\[ = \frac{1}{2} \times (\text{Max. Cut Width} + \text{Max. Cut Depth}) + \text{Overall height of the Road Miner} + \text{overall length Road Miner (for duct 1)}. \]
\[ = \frac{1}{2} \times (A&E + B) + F + C \]
\[ = 17.9 \text{ meter (49 feet)} \]

Another duct inlet is proposed to be installed above the three access hatch openings above the transverse conveyor. Length of Duct from this inlet to the cyclone (duct 2) = \( C/2 = 43.40/2 = 21.71 \) feet.

4.4.3.4 Frictional Pressure Loss in Ducts

It is proposed to have a 6" diameter duct to carry dusty air to the cyclone. Frictional losses can be found by referring to chart showing frictional losses for air in circular ducts U.S. customary units (adapted from ASHREA handbook as cited in Figure 8.2 Cooper and Alley 2002).

The frictional loss for air in 6 inch circular duct = 4.2 inches H\(_2\)O per 100 ft at 4000ft/min.

Total proposed duct length for Road Miner 1660 HD = 49 ft (duct 1) + 21.71 feet (duct 2) = 70.71 feet.

Therefore, pressure loss in straight duct = 70.71 feet x 4.2 inch / 100 ft = 2.969 inches H\(_2\)O.

4.4.3.5 Fitting Pressure Loss

Fitting pressure losses can be represented by: adding equivalent length of duct (the length of straight duct that would result in same pressure drop as the fitting) to actual duct length and then finding the total head loss due to friction.

Cooper and Alley (2002) gives equivalent straight duct lengths (as a multiplier of the duct diameter) to be considered for each fitting provided.

Fitting pressure loss can also be calculated as \( H_f = k_v \sqrt{v}/2g \).
where $K_i =$ Fitting pressure loss factor, dimensionless (shown in Table 4.7)

\[
V = \text{velocity in duct, ft/min}
\]

\[
g = \text{acceleration due to gravity, ft/sec}^2
\]

Adapted from Cooper and Alley (2002) equivalent straight duct length = 20 x 4"/
12" (foot) = 6.66 feet.

Number of elbows = 4 & number of tee's = 1

From Table 4.7 equivalent duct length = 45 x 4"/ 12" (foot) = 14 feet.

Therefore total head loss due to fitting pressure loss =

\[
= (6.66+14) \text{ feet} \times 4.2 \text{ inches H}_2\text{O per 100 ft} = 0.846 \text{ inches of H}_2\text{O}.
\]

Table 4.9 gives the summary of pressure losses in the proposed vacuum system

### Table 4.9

Summary of pressure losses in the proposed vacuum system

<table>
<thead>
<tr>
<th>Pressure loss $\Delta P$</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Acceleration loss</td>
<td>2</td>
<td>inches of H$_2$O</td>
</tr>
<tr>
<td>2 Entry loss</td>
<td>1.8</td>
<td>inches of H$_2$O</td>
</tr>
<tr>
<td>3 Frictional loss in straight duct</td>
<td>2.97</td>
<td>inches of H$_2$O</td>
</tr>
<tr>
<td>4 Fitting pressure loss</td>
<td>0.85</td>
<td>inches of H$_2$O</td>
</tr>
<tr>
<td><strong>Total pressure loss $\Delta P =</strong></td>
<td><strong>7.62</strong></td>
<td><strong>inches of H$_2$O</strong></td>
</tr>
</tbody>
</table>

### 4.5 Design of Cyclone

#### 4.5.1 Introduction

A cyclone is a cylindrical vortex chamber without moving parts that spins the gas stream in order to remove the entrained particles by centrifugal force.

The particle-laden gas enters the cyclone at the cylinder top, and is made to
spin by the shape of the gas entry. After entering the cyclone at the top, the gas forms a vortex with a high tangential velocity. This tangential velocity gives particles entrained in the gas a high centrifugal force, and propels them across the flow stream to the cyclone wall for collection. Collected dust descends the walls of the cyclone to the dust discharge at the bottom of the cone; primarily because of the downward component of gas velocity at the cyclone wall, rather than by gravitational force. The dusty air stream enters tangentially to the vacuum from the inlet and moves around the periphery.

Below the bottom of the gas exit duct, the spinning gas gradually migrates inwards to a central core along the cyclone axis, and from here up the gas exits from the cyclone chamber (Wang and Pereira, 1979).

Figure 4.6 shows a simplified line diagram of cyclone, where:

- $H$ = Height of inlet
- $S$ = Depth of outlet pipe
- $L_b$ = Length of cyclone
- $L_c$ = Length of Cone
- $D_d$ = Diameter of dust outlet
- $D_e$ = Diameter of outlet pipe

Figure 4.7 gives the direction of air flow.
Figure 4.6
Line diagram of Cyclone adapted from Cooper and Alley (2002).

Figure 4.7
Line diagram of cyclone showing airflow direction.

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4.5.2 Design Considerations

There are three main types of cyclones:

- High throughput
- Standard geometry
- High efficiency

Table 4.10 shows a high efficiency cyclone type gives the lowest pressure drop for a given flow rate and gives highest efficiency for a given pressure drop. Hence a high efficiency design was chosen for this application.

Table 4.10

Selection of cyclone type

<table>
<thead>
<tr>
<th>Cyclone type</th>
<th>High throughput</th>
<th>Standard geometry</th>
<th>High efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure drop for given air flow</td>
<td>lowest</td>
<td>medium</td>
<td>lowest</td>
</tr>
<tr>
<td>Efficiency for given pressure drop</td>
<td>lowest</td>
<td>medium</td>
<td>highest</td>
</tr>
</tbody>
</table>

Table 4.11 gives standard cyclone dimensional ratios for high efficiency cyclones that were derived from recommendations of two studies by Stairmand 1951 and Swift 1969, as cited in Cooper and Alley (2002).
Table 4.11

Cyclone dimensions as fraction of body diameter derived from Stairmand 1951 and Swift 1969, as cited in Cooper and Alley (2002).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>High Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stairmand 1951</td>
</tr>
<tr>
<td>Body Diameter D/D</td>
<td>1.00</td>
</tr>
<tr>
<td>Height of the inlet H/D</td>
<td>0.50</td>
</tr>
<tr>
<td>Width of the inlet W/D</td>
<td>0.20</td>
</tr>
<tr>
<td>Diameter of the Gas Exit De/D</td>
<td>0.50</td>
</tr>
<tr>
<td>Length of the vortex finder S/D</td>
<td>0.50</td>
</tr>
<tr>
<td>Length of the Body S/D</td>
<td>1.50</td>
</tr>
<tr>
<td>Length of the cone Lc/D</td>
<td>2.50</td>
</tr>
<tr>
<td>Diameter of the Dust Outlet Dd/ D</td>
<td>0.375</td>
</tr>
</tbody>
</table>

4.5.3 Collection Efficiency

Lapple (1941) produced a semi-empirical relationship to calculate the “50%” cut diameter \( (d_{pc}) \), defined as the diameter of particles collected with 50% efficiency:

\[
d_{pc} = \left[ \frac{9 \mu W}{2 \pi N_e V_i (\rho_p - \rho_g)} \right]^{1/2}
\]

Where \( \mu = \) gas viscosity, kg/m-s.

\( V_i = \) gas velocity inlet, m/sec.
W = width of inlet of cyclone, m.

$N_e =$ Number of effective turns.

$\rho_p =$ density of the particle, kg/m³.

$\rho_g =$ gas density, kg/m³.

The gas (dusty airflow) spins through a number of revolutions $N_e$.

$N_e = 1/H \left[ L_b + L_c/2 \right]$

Where

$N_e =$ Number of effective turns.

$H =$ height of inlet duct, m or feet.

$L_b =$ length of cyclone body, m or ft.

$L_c =$ length of cyclone cone, m or ft.

To be collected, particles must strike the wall within the amount of time that the gas travels in the outer vortex. The gas residence time in the outer vortex is:

$\Delta t = 2 \pi R N_e / V_i$

Where

$\Delta t =$ gas residence time, sec.

$R =$ cyclone body radius, meter.

$V_i =$ gas inlet velocity, m/sec.

Assuming that centrifugal force quickly accelerates particles to their terminal velocities in the outward (radial) direction; terminal velocity is achieved when the opposing drag force equals the centrifugal force.

Assumptions for dry air at:

Temperature = 100 Fahrenheit, 38°C
Viscosity of air = 1.94E-04 kg/m/sec
Viscosity of air = 1.17E-03 kg/m/min
Pressure = 1 Atm

A high-efficiency cyclone geometry is chosen as it has the lowest pressure drop and uses the least power for a given collection efficiency of the three major cyclone types.

A 1,113 cfm flow rate will give an inlet velocity at cyclone \( V_i = \frac{Q}{WH} \),

Where \( Q = \) flow rate of the system (centrifugal).

\( W = \) width of inlet of cyclone = \( (W/D) \times D = (0.20) \times 0.90 \text{ m} = 0.18 \text{ m} \).

\( H = \) height of inlet of cyclone = \( (H/D) \times D = (0.40) \times 0.90 \text{ m} = 0.36 \text{ m} \).

\( Q = 1113 \text{ cfm} = \frac{1113}{(3.28^3)} \text{ m}^3/\text{min} = 31.54 \text{ m}^3/\text{min} \).

\( V_i = \frac{31.54 \text{ m}^3/\text{min}}{(0.18 \text{ m} \times 0.45 \text{ m})} = 778.19 \text{ m/min} \) (Stairmand Geometry).

Diameter of circular duct = 6 inches
Conversion = /12 inches/foot
Conversion = /3.28 foot/meter
Diameter of duct = 0.15 meter
Area of duct = 0.18 \( \text{m}^2 \)
Flow rate provided = 1113 cfm
Conversion = 0.28 \( \text{m}^3/\text{ft}^3 \)
Flow rate provided at duct = 31.52 \( \text{m}^3/\text{min} \)
Velocity provided in duct = 1728 m/min
Conversion = 3.28 ft/m
Velocity provided in duct = 5668 ft/min

Using this velocity, pressure drop and volumetric flow to be handled by the cyclone is found in Table 4.12.
Table 4.12

Calculation of pressure drop for 0.90 m cyclone diameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate(= Q =)</td>
<td>1,113</td>
<td>CFM</td>
</tr>
<tr>
<td>Blower capacity</td>
<td>31.52</td>
<td>m³/min</td>
</tr>
<tr>
<td>Number of ducts</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Net maximum flow rate produced</td>
<td>63.03</td>
<td>m³/min</td>
</tr>
<tr>
<td>Area of cyclone inlet</td>
<td>0.081</td>
<td>m²</td>
</tr>
<tr>
<td>Velocity = flow rate/area</td>
<td>778.19</td>
<td>m/min</td>
</tr>
<tr>
<td>Inlet gas velocity at cyclone(= V_i =)</td>
<td>12.97</td>
<td>m/sec</td>
</tr>
<tr>
<td>Density of air(= \rho_g =)</td>
<td>1.08</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Pressure drop in cyclone = (\Delta P = \frac{1}{2} \rho_g V_i^2 H_v) (\sim)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where \(H_v = k HW/De^2\)

| With k =                                           | 16            | constant (***) |
| Diameter of gas exit for cyclone = \(D_e =\)       | 0.45          | m           |
| Height of inlet for cyclone = \(H =\)             | 0.45          | m           |
| Width of inlet for cyclone = \(W =\)              | 0.18          | m           |
| \(H_v = k HW/De^2\)                                | 6.4           | number of inlet velocity heads (*) |
| Pressure drop = \(\Delta P = \frac{1}{2} \rho_g V_i^2 H_v\) | 581           | N/m² (Pa)  |
| Conversion factor                                  | 249           | Pa/atm in H₂O |
| Pressure drop = \(\Delta P = \frac{1}{2} \rho_g V_i^2 H_v\) | 2.33          | Atm in H₂O  |
| \(Q = \text{Volumetric flow rate} =\)             | 2226          | CFM (2 blowers, 1113 CFM each) |
| \(Q = \text{Volumetric flow rate} =\)             | 62.07         | m³/min     |
| \(Q = \text{Volumetric flow rate} =\)             | 1.035         | m³/sec     |

\(\sim\) Cited from Cooper and Alley, 2002.

\(*)\) Shepherd and Lapple Equation as cited in Cooper and Alley, 2002.
First trial of cyclone design was performed using a cyclone diameter of 0.90 m. The overall dimensions of the cyclone were obtained from the ratios given in Table 4.11. The total overall dimensions so obtained, were checked to make sure they could be retrofitted on a Road Miner 1660 HD.

Table 4.13 shows proposed cyclone design using techniques described in "Air Pollution Control: A Design Approach" Cooper and Alley 2002, and using cyclone "configurations", first developed by Stairmand (1951) and Swift (1969) as cited in Cooper and Alley, 2002.
Table 4.13

<table>
<thead>
<tr>
<th>#</th>
<th>Description</th>
<th>Unit</th>
<th>Stairmand</th>
<th>Fisher Klosterman inc</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$D =$ Diameter of the cyclone</td>
<td>m</td>
<td>0.9</td>
<td>0.6858</td>
</tr>
<tr>
<td>2</td>
<td>Velocity inlet $= Q / (WH)$</td>
<td>m/sec</td>
<td>12.97</td>
<td>19.27</td>
</tr>
<tr>
<td>3</td>
<td>$W =$ width of cyclone inlet</td>
<td>m</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$H =$ Height of cyclone inlet</td>
<td>m</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$A =$ Area of cyclone inlet</td>
<td>m$^2$</td>
<td>0.081</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Length of the Body S/D (Lb)</td>
<td>m</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Length of the cone Lc/D</td>
<td>m</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Density of particle kg/m$^3 = P_p$</td>
<td>kg/m$^3$</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>9</td>
<td>Air Density kg/m$^3 = P_g$</td>
<td>kg/m$^3$</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>10</td>
<td>Total Height</td>
<td>m</td>
<td>3.6</td>
<td>2.17</td>
</tr>
<tr>
<td>11</td>
<td>Number of effective turns $= N_e$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>$N_e = 1 / H [Lb + Lc/2]$</td>
<td>Turns</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Air Viscosity</td>
<td>kg/m sec</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>$t = 2 \pi R N_e / V_i$</td>
<td>sec</td>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Design particle size $= d_{pc}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Numerator $= 9 \mu W$</td>
<td></td>
<td>1.89x 10$^{-03}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Denominator $= 2 \pi N_e V_i (P_p - P_g)$</td>
<td></td>
<td>6.72x 10$^{07}$</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>$d_{pc} = {(9 \mu W) / (2 \pi N_e V_i (P_p - P_g))}^{1/2}$</td>
<td>micsrons</td>
<td>5.3</td>
<td>5.0</td>
</tr>
<tr>
<td>17</td>
<td>Pressure drop</td>
<td>ln H$_2$O</td>
<td>2.33</td>
<td></td>
</tr>
</tbody>
</table>

Stairmand$^1$ as per recommendations from Stairmand, 1941 as cited in Cooper and Alley 2002.

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Fisher Klosterman Inc.

The design particle size, dpc, captured at 50% by the cyclone from calculations is 5.3 microns < 10 microns (target particle size).

4.5.4 Cyclone Power Requirement

The next step would be to calculate power requirement for the vacuum system.

Fluid Power required is given by:

\[ \text{Power required} = W_f = 0.0001575 \cdot Q \cdot \Delta P \]

Where

\( W_f = \text{fluid power, hp} \)

0.0001575 is a conversion factor (hp/ (ft\(^3\)/min in H\(_2\)O))

\( Q = \text{air flow rate, cfm} \)

\( \Delta P = \text{total pressure loss} = \frac{1}{2} \rho_g v_i^2 H_v \) (Pascal)

Where

\( \rho_g = \text{gas density, kg/m}^3 \)

\( V_i = \text{inlet velocity m/sec} \)

249 Pascal = 1 \( \Delta P \) (inch H\(_2\)O)

\( H_v = \text{number of velocity heads} = k \cdot \frac{H \cdot W}{D_e^2} \)

Where

\( K = \text{constant. Licht (1984) as cited in Cooper and Alley (2002) recommends K to be set to16.} \)

\( H = \text{height of inlet (inches)} \)

\( W = \text{width of inlet (inches)} \)
\[ D_e = \text{diameter of duct outlet (inches)} \]

Value of velocity heads \( H_v = k \frac{HW}{D_e^2} \)

\[
= 16 \times 0.18 \times 0.44 / (0.33)^2 = 6.54 \quad \text{(Stairmand, 1941)} \\
= 16 \times 0.189 \times 0.396 / (0.33)^2 = 6.18 \quad \text{(Swift, 1969)}
\]

\( \Delta P = \text{total pressure loss, in } H_2O = \Delta P_{\text{cyclone}} + \Delta P_{\text{Ducts}} \)

\( \Delta P_{\text{cyclone}} = 2.33 \text{ inches of water} \)

\( \Delta P_{\text{Ducts}} = 7.62 \text{ inches of water} \)

\( \Delta P = \text{total pressure loss, in } H_2O = 9.95 \text{ inches of water} \)

Flow rate = 1,113*2 = 2,226 cfm

Fluid Power required =0.0001575(conversion factor)* 2226(cf m) * 9.95 (inches of water) = 3.48 Hp

Considering Overall efficiency = 60%

Estimated brake horsepower = 3.48 / 0.60 = 5.81 Bhp

The Trencon Road Miner is rated at maximum of 750 hp @ 2100 rpm. Most of the time it hardly uses \% of its rating, because of soil conditions and speed of excavation. A parasitic loss of 5.81 hp in 740 hp has to be verified as acceptable by the manufacturers of Road Miner.

4.6 Collection Efficiency of Cyclone

The particle size distribution from the hydrometer test of the soil sample collected from the field visit to Rhodes Ranch is represented in the first two columns of Table 4.14. These results are used as input to find cut size of particle diameter to be captured by cyclone.
Table 4.14

Efficiency Calculations for Stairmand cyclone at dpc = 5.3 μm

<table>
<thead>
<tr>
<th>Particle Size dpj, μm</th>
<th>dpc/dpj μm</th>
<th>Mass percentage Size range % mj, %</th>
<th>Efficiency for individual size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finer than 3 μm</td>
<td></td>
<td>21.30</td>
<td></td>
</tr>
<tr>
<td>3.08</td>
<td>0.299</td>
<td>6.00</td>
<td>0.918</td>
</tr>
<tr>
<td>4.33</td>
<td>0.213</td>
<td>8.00</td>
<td>0.957</td>
</tr>
<tr>
<td>6.09</td>
<td>0.151</td>
<td>10.00</td>
<td>0.978</td>
</tr>
<tr>
<td>8.41</td>
<td>0.110</td>
<td>20.00</td>
<td>0.988</td>
</tr>
<tr>
<td>11.63</td>
<td>0.079</td>
<td>2.00</td>
<td>0.994</td>
</tr>
<tr>
<td>15.32</td>
<td>0.060</td>
<td>2.00</td>
<td>0.996</td>
</tr>
<tr>
<td>21.05</td>
<td>0.044</td>
<td>4.00</td>
<td>0.998</td>
</tr>
<tr>
<td>28.66</td>
<td>0.032</td>
<td>12.00</td>
<td>0.999</td>
</tr>
<tr>
<td>39.62</td>
<td>0.023</td>
<td>4.00</td>
<td>0.999</td>
</tr>
<tr>
<td>51.98</td>
<td>0.018</td>
<td>2.00</td>
<td>1.000</td>
</tr>
<tr>
<td>68.97</td>
<td>0.013</td>
<td>8.70</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100.00</td>
<td>68.655</td>
</tr>
</tbody>
</table>

Table 4.14 shows the calculation of estimated overall cyclone collection efficiency (gives the data used to calculate the efficiency of cyclone).

The estimated efficiency of the Stairmand cyclone comes up to 68%.

The particle size distribution, flow rate, desired pressure drop and maximum allowable dimensions were sent to Fisher Klosterman Inc, Louisville, KY, USA, to obtain a quote of a commercially available design. The efficiency given by Fisher Klosterman Inc is shown in Table 4.15 gives an efficiency of 91%.

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Table 4.15
Cyclone efficiency of cyclone provided by Fisher Klosterman Inc at dpc = 5.3 μm

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Mass Percentage</th>
<th>Efficiency for individual size = (1/(1+ (d_{pc}/d_{pj})^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size Range</td>
<td>(m_j%)</td>
</tr>
<tr>
<td>dpj microns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>31.83</td>
<td>0.73</td>
</tr>
<tr>
<td>3.08</td>
<td>12.14</td>
<td>0.92</td>
</tr>
<tr>
<td>4.33</td>
<td>6.29</td>
<td>0.96</td>
</tr>
<tr>
<td>6.09</td>
<td>6.56</td>
<td>0.98</td>
</tr>
<tr>
<td>8.41</td>
<td>4.91</td>
<td>0.99</td>
</tr>
<tr>
<td>11.63</td>
<td>6.74</td>
<td>0.99</td>
</tr>
<tr>
<td>15.32</td>
<td>11.25</td>
<td>1.00</td>
</tr>
<tr>
<td>21.05</td>
<td>7.56</td>
<td>1.00</td>
</tr>
<tr>
<td>28.66</td>
<td>7.20</td>
<td>1.00</td>
</tr>
<tr>
<td>39.62</td>
<td>7.20</td>
<td></td>
</tr>
</tbody>
</table>

Summary of design:

1. Hood over cutting head: \(\frac{1}{2}\) Diameter of the shroud over cutting head

2. Centrifugal Blowers -

Two Centrifugal New York Blower Company 146 KA pressure blower each rated at 2.94 Bhp at 12" of pressure drop in water column for 1,113 cfm.

- Location 1 One end of Cutting head.
- Location 2 Directionally opposite side of location immediately after hood entrance.
- Location 3 Below the transfer point where central conveyor dumps on to transverse conveyor.
• Location 4  Immediately above transfer point of central conveyor to transverse conveyor.

3. Ducting 6” diameter galvanized steel pipes with flexible fittings.

4. Cyclone:

Stairmand cyclone geometry is as follows:

\[ D = \text{Diameter of the cyclone} \quad 0.9 \quad \text{m} \]
\[ W = \text{width of inlet duct} \quad 0.18 \quad \text{m} \]
\[ H = \text{Height of inlet duct} \quad 0.45 \quad \text{m} \]
\[ \text{Length of the Body S/D (Lb)} \quad 1.35 \quad \text{m} \]
\[ \text{Length of the cone Lc/D} \quad 2.25 \quad \text{m} \]

Fisher Klosterman cyclone geometry is as follows:

\[ D = \text{Diameter of the cyclone} \quad 0.686 \quad \text{m} \]
\[ \text{Overall height of the cyclone} \quad 2.17 \quad \text{m} \]

4.7 Cost of Vacuum System

Table 4.16 gives the cost breakdown of Vacuum system
Table 4.16

Estimated Vacuum System Costs

<table>
<thead>
<tr>
<th>Vacuum System Cost</th>
<th>Components</th>
<th>Qty</th>
<th>Unit</th>
<th>Unit cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hoods</td>
<td></td>
<td>Sq. foot</td>
<td>$126.00</td>
<td>$126.00</td>
</tr>
<tr>
<td>2</td>
<td>Labor for fabricating hood</td>
<td></td>
<td>Hours</td>
<td>$60.00</td>
<td>$180.00</td>
</tr>
<tr>
<td>3</td>
<td>Air Knives</td>
<td></td>
<td>Each</td>
<td>$620.00</td>
<td>$2480.00</td>
</tr>
<tr>
<td>4</td>
<td>Centrifugal blowers</td>
<td></td>
<td>Each</td>
<td>$620.00</td>
<td>$2480.00</td>
</tr>
<tr>
<td>5</td>
<td>Ducting</td>
<td></td>
<td>Each</td>
<td>$6.49</td>
<td>$467.28</td>
</tr>
<tr>
<td>6</td>
<td>Cyclone</td>
<td></td>
<td>Each</td>
<td>$200.00</td>
<td>$200.00</td>
</tr>
<tr>
<td>7</td>
<td>subtotal (1 through 6)</td>
<td></td>
<td></td>
<td></td>
<td>$12,833.28</td>
</tr>
<tr>
<td>8</td>
<td>Labor for installation</td>
<td></td>
<td>Hours</td>
<td>$60.00</td>
<td>$960.00</td>
</tr>
<tr>
<td>9</td>
<td>Overhead 50 % of labor</td>
<td></td>
<td></td>
<td>$320.00</td>
<td>$320.00</td>
</tr>
<tr>
<td>10</td>
<td>subtotal (7 through 9)</td>
<td></td>
<td></td>
<td></td>
<td>$14,113.28</td>
</tr>
<tr>
<td>11</td>
<td>Markup and profit 70 %</td>
<td></td>
<td></td>
<td>$9,879.30</td>
<td>$9,879.30</td>
</tr>
<tr>
<td>12</td>
<td>Total (10 + 11)</td>
<td></td>
<td></td>
<td></td>
<td>$23,992.58</td>
</tr>
</tbody>
</table>

Cost of Hood is derived from EPA Manual on Dec 15 2003

http://www.epa.gov/tnn/catc/dir1/c_allchs.pdf

Labor cost for welding and fabricating obtained from Steel Engineers, Las Vegas Nevada = $60/hour on Oct 22 2004.

Cost of air knife obtained on Oct 22 2004 from
4.8 Design of Water Spray System

One type of alternative dust suppression system is a water spray system attached directly to the equipment in use. This water spray system works integrally with the equipment operations to provide suppression directly at the source of dust emissions. The components for such a system include spray nozzles, connected by a network of tubing or pipe with an onboard pump and tank to supply the water (Gambatese and James, 2001).

Figure 4.7 shows the schematic of a water spray system on a Chain Trencher.

4.8.1 Design Considerations

Careful consideration in the design of water spray system for dust suppression is needed for:

- Water droplet size
- Agglomeration
- Selection and geometry of type of spray nozzle
- Water consumption rate, location and capacity equipment water tank
- Piping
- Pump design
Figure 4.8

Schematic of water spray system for Chain Trencher – dark triangles show expected spray coverage (Sketch drawn by author)
4.8.1.1 Water Droplet Size

Water droplet size has been shown to be an important factor in dust suppression effectiveness (Carter 1995 as cited in Gambatese and James (2001). If droplets are too large, smaller dust particles generally just “slipstream” around the droplets without contact. On the other hand, droplets that are too small just mix and circulate with the dust particles without wetting them.

Gambatese and James (2001) found that a low pressure, low flat rate spray system having spray nozzle diameter of approximately 15.9 mm (5/8 in.) made clogging less of a problem, required less maintenance and emitted droplets ranging from approximately 2 μm to 300 μm, depending on the system pressure, with an average droplet size of approximately 30 μm.

Two columns of spray nozzles were mounted on each side of the dump truck. With a stop distance of 1.22 m (4’), water droplets were carried across the seven-foot wide bed of a dump truck. Using a pressure of 40 psi and 0.013 m³/min, Gambatese and James found that the capture rate of PM-10 was significant (an average of 32.43% decrease in PM-10 emission), in design wind speeds of less than 25 km/hour.

4.8.1.2 Agglomeration

Control of dust is provided through agglomerate formation by either combining small dust particles with larger aggregates or by capturing liquid droplets (Cowherd et al. 1990). The key factors that affect the degree of agglomeration are the coverage of the material by the liquid and the ability of the liquid to “wet” small particles (Cowherd et al. 1990).
4.8.1.3 Selection of Type of Spray Nozzle

Water spray design begins with selection of type of spray nozzle to be mounted. Vendor sheets or manufacturer catalog gives different types of spray nozzles with common application and details such as:

- Spray angles
- Capacity in gallons per minute for specified pressure.
- Included spray angle
- Theoretical coverage at various distances from nozzle orifice

For example water spray nozzles are to be selected for an application such as fugitive dust suppression would be Fulljet© spray nozzles. These nozzles feature a solid cone-shaped spray pattern with round impact area (Vendor sheets, C32, Spraying systems Co©, 1994).

Design specifications for water spray systems to control dust have not been established in standard practice and are typically based on the experience of the design engineer (Cowherd et al. 1990, as cited in Gambatese and James 2001). Here are some of the general guidelines suggested by Gambatese and James 2001:

- Optimal droplet size for surface impaction and fine particle agglomeration is approximately 500 μm.
- Very small water droplets are less effective because they are affected by wind and surface tension.
- Wetting the surface on which transferred material is placed improved the system performance (Gambatese and James, 2001).
4.8.1.4 Geometry of Spray Nozzle System

Table 4.17 gives the manufacturer's specification for spray configuration, theoretical coverage and spray distance for solid cone spray nozzles. Figure 4.9 and Figure 4.10 gives the line diagram for spray configuration.

A 50% spray overlap design objective was established in order to increase the probability of capture. Also, in case one of the nozzles gets clogged the other two adjacent nozzles may cover for the empty space that remains vacant.

The number of spray nozzles required is \( L = \frac{\text{length of the dust source of equipment}}{C} + 1 \) (to add for spaces).

Figure 4.9
Spray configuration (Sketch drawn by author)
Figure 4.10

Configuration at 50% overlap (Sketch drawn by author)

Included spray angle and corresponding theoretical coverage at various distances (in Inches) from the nozzle retrieved from Vendor data sheets, page C32, Spraying systems Co©, 1994 are shown in Table 4.17.
Table 4.17
Included spray angle and corresponding theoretical coverage at various distances (in Inches) from the nozzle.

<table>
<thead>
<tr>
<th>Included spray angle</th>
<th>Theoretical Coverage at Various Distances (in Inches) from the Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10&quot;</td>
</tr>
<tr>
<td>Spray Coverage (inches)</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>9.3</td>
</tr>
<tr>
<td>60</td>
<td>11.5</td>
</tr>
<tr>
<td>65</td>
<td>12.7</td>
</tr>
<tr>
<td>70</td>
<td>14.0</td>
</tr>
<tr>
<td>75</td>
<td>15.3</td>
</tr>
<tr>
<td>80</td>
<td>16.8</td>
</tr>
<tr>
<td>85</td>
<td>18.3</td>
</tr>
<tr>
<td>90</td>
<td>20.0</td>
</tr>
<tr>
<td>95</td>
<td>21.8</td>
</tr>
<tr>
<td>100</td>
<td>23.8</td>
</tr>
<tr>
<td>110</td>
<td>28.5</td>
</tr>
<tr>
<td>120</td>
<td>34.6</td>
</tr>
</tbody>
</table>


For example:

A Trencor Chain Trencher 1260 HD has a boom of 12 feet. A spray nozzle with an included angle 80 degrees placed at a distance of 36" from the top of the boom will theoretically cover about 60" long area. Considering 50% overlap, coverage will be equal to 30" (2.5 feet). The number of spray nozzles required = 12/2.5 = 4.8 ~ 5 nozzles equally spaced + one nozzle at the end = 6 spray nozzles.

In addition the transverse conveyor needs one spray nozzle at each end. So the total number spray nozzles required = 6+1+1 = 8. Of these 7 would be active at
any time. The nozzle on the non-projecting side of the transverse conveyor would be shut down. The next step would be to decide the capacity and location of add-on water tank.

4.8.1.5 Water Tank Location and Capacity

A system that requires a large amount of water but has a small supply tank will require the tank to be refilled frequently. Frequent refilling decreases the overall productivity of the construction operation and negatively impacts project success. The system should be designed such that refilling is required infrequently. The number of times the tank will need to be refilled can be related to the water consumption rate of the system (Gambatese and James, 2001).

Excavation using Chain Trenchers and Road Miners is a continuous operation. The criteria determining refill frequency and water tank capacity include flow rate and the weight of water tank when full.

For example if each spray nozzle (included angle 80 degrees) requires 0.6 gpm of water at 10 psi, the number of spray nozzles multiplied by water consumption per nozzle will give the total flow requirement in gallons per minute (gpm) for the system. Considering refill frequency of one hour, water tank size required = 7 spray nozzles x 0.6 (gallons per minute) x 60 (mins/ hour) = 252 gallons. To meet the 1-hour requirement and provide some reserve, it is proposed to provide a 325-gallon on-equipment water tank.

This weight of water tank (when full) needs to be balanced so as not to leverage or hamper any of the regular excavation, mobility and transportation or any kind of operating ease.
Figures 4.11 and 4.12 show different proposed locations and their feasibility of installing an add-on water tank.

Figure 4.11


1. Vacant place, not good, directly over the engine may trickle water into moving parts of engine.

3 Boom not suitable: moving parts, susceptible to vibrations and damage from flying stone particles.

Ideal locations for water tank and water pump, not a hindrance to any access.

- Repair and maintenance hatch for engine, can't be blocked.
A water tank manufactured by American Tank Company is 45" long, 47" wide and 45" high and has capacity 325 gallons, can be retrofitted parallel to operator's cabin as shown in Figure 4.12.

To estimate mechanical load, one gallon of water weighs about 8.34 lbs; therefore when full, a 325 gallon tank will weigh = 8.34 lbs/(gallon) x 325 (gallons) 2710 lbs in addition to the tank empty weight of 150 lbs (total of 2860 lbs).
For Chain Trencher and the Road Miner, the vacant space directly beside the operator's cabin would be the potential ideal location for installing a water tank. This location is not prone to flying rock fragments. Also, being centrally located will help to maintain balance on slopes.
4.8.1.6 Piping

Piping will be required to convey water from water tank to the spray nozzles. Flexible hose piping generally used for pressure washers is readily available, inexpensive, needs fewer fixtures and can withstand high pressure. A 9.5 mm (3/8 in.) diameter high-pressure flexible hose was selected to run from water pump to the spray nozzles.

The next step is to calculate capacity of pump required.

4.8.1.7 Pump Design and Selection

From the geometry and spray configuration a total of seven operating nozzles are required, hence the maximum total flow requirement of the system would be 7.7 gallon per minute (1.1 gallons per minute at 40 psi per nozzle).

Both reciprocating and rotary pumps are capable of delivering product at extremely low flow rates. Table 4.16 gives the comparison of pump selection.

Power required for the pump can be calculated as:

Total power needed for pump = power required to overcome frictional losses +

power required to pump total flow required.

= flow rate (Q) x total pressure drop (Δp)

Total pressure drop (Δp) = Σ frictional head loss (f l v^2/ 2 g d) + pressure drop for all nozzles (Σ nozzles * Δp each nozzle)

Frictional head losses can be calculated by Darcy-Weisbach Equation:
Head\(_{loss}\) = f \( l \sqrt{\frac{v^2}{2g}} d \). Pressure drop for nozzles are obtained from manufacturers catalog.

For electric pumps, allowing for impeller losses, shaft friction losses, winding losses, we'd divide the fluid power requirement by about \( \frac{1}{2} \) horsepower pump. This pump can be electric pump deriving power from the equipment or gasoline engine pump attached on to the equipment.
Table 4.18

Selection criteria for water pump

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rotary Pumps</th>
<th>Reciprocating Pumps</th>
<th>Centrifugal Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum Flow and Pressure</td>
<td>Low/ Medium Capacity, Low/Medium Pressure</td>
<td>Low Capacity, High Pressure</td>
<td>Medium/ High Capacity, Low/Medium Pressure</td>
</tr>
<tr>
<td>Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Flow Rate</td>
<td>100,00 GPM</td>
<td>10,000+ GPM</td>
<td>100,000+ GPM</td>
</tr>
<tr>
<td>Low Flow Rate Capability</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maximum Pressure</td>
<td>4,000+ PSI</td>
<td>100,000+ PSI</td>
<td>6,000+ PSI</td>
</tr>
<tr>
<td>Requires Relief Valve</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Smooth or Pulsating Flow</td>
<td>Smooth</td>
<td>Pulsating</td>
<td>Smooth</td>
</tr>
<tr>
<td>Variable or Constant Flow</td>
<td>Constant</td>
<td>Constant</td>
<td>Variable</td>
</tr>
<tr>
<td>Self-priming</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Space Considerations</td>
<td>Requires Less Space</td>
<td>Requires More Space</td>
<td>Requires Less Space</td>
</tr>
<tr>
<td>Costs</td>
<td>Lower Initial</td>
<td>Higher Initial</td>
<td>Lower Initial</td>
</tr>
<tr>
<td></td>
<td>Lower Maintenance</td>
<td>Higher Maintenance</td>
<td>Lower Maintenance</td>
</tr>
<tr>
<td></td>
<td>Lower Power</td>
<td>Lower Power</td>
<td>Higher Power</td>
</tr>
<tr>
<td>Fluid Handling</td>
<td>Requires clean, clear, non-abrasive fluid due to close tolerances Optimum performance with high viscosity fluids Higher tolerance for entrained gases</td>
<td>Suitable for clean, clear, non-abrasive fluids. Specially-fitted pumps suitable for abrasive-slurry service. Suitable for high viscosity fluids Higher tolerance for entrained gases</td>
<td>Suitable for a wide range including clean, clear, non-abrasive fluids to fluids with abrasive, high-solid content. Not suitable for high viscosity fluids Lower tolerance for entrained gases</td>
</tr>
</tbody>
</table>

Retrieved September 15 2004 from:

(http://www.pdhengineer.com/Course%20Files/Completed%20Course%20PDF%20Files/Pumps%20Centrifugal%20vs%20Positive%20Displacement%20Word%20Document.htm).

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4.8.2 Sample Preliminary Design for Trencor Road Miner

The direct sources of dust emission on Road Miner are the cutting drum and the transverse conveyor dumping soil on to the ground. Water sprays are proposed to be mounted on the hood (shroud that covers the cutting head drum) and mounted overhanging by welded connection on each side of the transverse conveyor.

The water spray needs to have as coverage equivalent to the maximum depth of the cut corresponding to the diameter of cutting drum. For dust suppression the manufacture/ vendor sheets recommend using a solid cone spray nozzle configuration.

Following are the preferred specifications for the Road Miner water spray system:

- Spray angle 80 degrees
- Capacity in gallons per minute for specified pressure = 1.1 gpm at 40 psi.
- Theoretical coverage at various distances from nozzle orifice = 86 "at a distance of 48" from the nozzle head (orifice) to the lowest point of cutting drum of the Road Miner. Table 4.19 gives sample calculations for spray configuration on different models of Trencor Road Miner.

Row B in Table 4.19 corresponds to the height of water spray needs to cover. The width of cutting drum will determine the width and spacing of water sprays. The methodology is similar to covering the boom length of the trencher. Table 4.19 gives a sample calculation of number of sprays required for different models...
of Trencor Road Miner and Table 4.20 gives the sample calculation of number of sprays required for different models of Trencor Chain Trencher.

Table 4.19

Sample calculations for spray configuration on different models of Trencor Road Miner

<table>
<thead>
<tr>
<th>DIMENSIONS</th>
<th>1260HD</th>
<th>1460HD</th>
<th>1660HD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meters</td>
<td>Feet</td>
<td>Meters</td>
</tr>
<tr>
<td>A Max. Cut Width</td>
<td>3.2</td>
<td>10'-6&quot;</td>
<td>3.8</td>
</tr>
<tr>
<td>B Max. Cut Depth</td>
<td>0.91</td>
<td>3'-0&quot;</td>
<td>1.2</td>
</tr>
<tr>
<td>C Overall Length</td>
<td>8.7</td>
<td>28'-6&quot;</td>
<td>11.1</td>
</tr>
<tr>
<td>D Crawler Length</td>
<td>4.6</td>
<td>15'-0&quot;</td>
<td>5.6</td>
</tr>
<tr>
<td>E Overall Width</td>
<td>3.2</td>
<td>10'-6&quot;</td>
<td>3.8</td>
</tr>
<tr>
<td>F Overall Height</td>
<td>3.2</td>
<td>10'-7&quot;</td>
<td>3.7</td>
</tr>
<tr>
<td>G Track Width</td>
<td>2.9</td>
<td>9'-6&quot;</td>
<td>3.5</td>
</tr>
<tr>
<td>H coverage</td>
<td>60.4</td>
<td>Inches</td>
<td>80.6</td>
</tr>
<tr>
<td>Distance from Orifice</td>
<td>36&quot;</td>
<td>Inches</td>
<td>48&quot;</td>
</tr>
<tr>
<td>Number of nozzles reqd. for cutting head = (A/2) / H</td>
<td>4.17</td>
<td>#</td>
<td>3.77</td>
</tr>
<tr>
<td>Round off</td>
<td>4</td>
<td>#</td>
<td>4</td>
</tr>
<tr>
<td>Number of spray nozzles for transverse conveyor =</td>
<td>2</td>
<td>#</td>
<td>2</td>
</tr>
<tr>
<td>Total number of spray nozzles needed</td>
<td>6</td>
<td>#</td>
<td>6</td>
</tr>
<tr>
<td>Discharge per nozzle @ 40 psi</td>
<td>1.1</td>
<td>GPM</td>
<td>1.1</td>
</tr>
<tr>
<td>Water tank refill frequency</td>
<td>50</td>
<td>Minutes</td>
<td>50</td>
</tr>
<tr>
<td>Total water tank capacity</td>
<td>325</td>
<td>Gallons</td>
<td>325</td>
</tr>
</tbody>
</table>
As discussed earlier a 9.5 mm (3/8 in.) diameter high-pressure flexible hose will be run from water pump to the spray nozzles.

Table 4.20
Sample calculations for spray configuration on different models of Trencor Chain Trencher.

<table>
<thead>
<tr>
<th>Trencor Chain Trencher Model numbers</th>
<th>1260HD</th>
<th>1460HD</th>
<th>1660HD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIMENSIONS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Max. Cut Width</td>
<td>1.07</td>
<td>1.22</td>
<td>1.52</td>
</tr>
<tr>
<td>B Max. Cut Depth</td>
<td>3.659</td>
<td>4.878</td>
<td>6.098</td>
</tr>
<tr>
<td>Distance from Orifice</td>
<td>144</td>
<td>192</td>
<td>240</td>
</tr>
<tr>
<td>coverage</td>
<td>60.4</td>
<td>80.6</td>
<td>80.6</td>
</tr>
<tr>
<td>number of nozzles reqd.</td>
<td>5.77</td>
<td>5.76</td>
<td>6.96</td>
</tr>
<tr>
<td>Round off</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Add one nozzle for space</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spray nozzles for transverse conveyor</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total Spray nozzles</td>
<td>9</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>GPM for Nozzle inlet 1/4&quot; at 10 psi</td>
<td>0.60</td>
<td>0.60</td>
<td>0.6</td>
</tr>
<tr>
<td>Water consumption GPM</td>
<td>5.26</td>
<td>5.26</td>
<td>5.97</td>
</tr>
<tr>
<td>Water consumption gallon per hour</td>
<td>315.66</td>
<td>315.51</td>
<td>358.39</td>
</tr>
</tbody>
</table>

**NOTE:** B Max. Cut Depth = maximum distance that water spray has to travel from orifice of the nozzle.
Table 4.21 gives the total power requirement of water pump for different models of Trencor Road Miner. These calculations are made for five solid cone spray nozzles, having internal spray angle of 80 degrees, attached to the equipment.

Table 4.21

Power requirements of water pump for different models of Trencor Road Miner.

<table>
<thead>
<tr>
<th>Flow rate</th>
<th>Pressure</th>
<th>Total Power required for water pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q per nozzle</td>
<td>Q Total</td>
<td>ΔP</td>
</tr>
<tr>
<td>GPM</td>
<td>GPM</td>
<td>PSI</td>
</tr>
<tr>
<td>0.60</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>0.83</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>0.99</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td><strong>1.10</strong></td>
<td><strong>10</strong></td>
<td><strong>40</strong></td>
</tr>
<tr>
<td>1.40</td>
<td>13</td>
<td>60</td>
</tr>
<tr>
<td>1.60</td>
<td>14</td>
<td>80</td>
</tr>
<tr>
<td>1.70</td>
<td>15</td>
<td>100</td>
</tr>
</tbody>
</table>

The maximum fluid power requirement for water spray system on a Trencor Road Miner 1660 HD would be about 1427 watts at a flow rate of 1.10 GPM under a pressure drop of 40 psi.

Summary of design: Water spray system for Road Miner 1660 HD.

- Water tank capacity = 320 gallons.

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- Water pump: electrical reciprocating pump, capacity 1.5 horse power (to accommodate for any frictional losses, head loss, system losses and provide excess power in case of increased pressure or flow rate.
- Piping: 9.5 mm (3/8 in.) diameter Pressure hose.
- Sprays: 5, 80° internal angle FullJet© Spray nozzle manufactured by The Spraying System Co©.

Table 4.22 gives the cost of installing a water spray system on Road Miner 1660 HD.
### Table 4.22

**Water spray system cost 2003 Dollars**

<table>
<thead>
<tr>
<th>Components</th>
<th>Number</th>
<th>unit Cost</th>
<th>Cost</th>
<th>Life</th>
<th>O&amp;M Times replaced in 2 years</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water sprays</td>
<td>5</td>
<td>$26.88</td>
<td>$134.38</td>
<td>1</td>
<td>2</td>
<td>$268.75</td>
</tr>
<tr>
<td>2. Water Pressure hose 100' length</td>
<td>1</td>
<td>$139.74</td>
<td>$139.74</td>
<td>1</td>
<td>2</td>
<td>$279.48</td>
</tr>
<tr>
<td>3. Water pump</td>
<td>1</td>
<td>$139.75</td>
<td>$139.75</td>
<td>1</td>
<td>2</td>
<td>$279.50</td>
</tr>
<tr>
<td>4. Water tank</td>
<td>1</td>
<td>$548.24</td>
<td>$548.24</td>
<td>2</td>
<td>1</td>
<td>$548.24</td>
</tr>
<tr>
<td>5. Installation &amp; labor lumpsum</td>
<td></td>
<td></td>
<td>$1,000.00</td>
<td>1</td>
<td>2</td>
<td>$200.00</td>
</tr>
<tr>
<td>6. Valves &amp; Fittings lumpsum</td>
<td></td>
<td></td>
<td>$200.00</td>
<td>2</td>
<td>1</td>
<td>$200.00</td>
</tr>
<tr>
<td>7. Over head 50% of Labor</td>
<td></td>
<td></td>
<td>$500.00</td>
<td>2</td>
<td>1</td>
<td>$100.00</td>
</tr>
<tr>
<td>8. Subtotal</td>
<td></td>
<td></td>
<td>$2,622.10</td>
<td>1</td>
<td></td>
<td>$1,875.97</td>
</tr>
<tr>
<td>9. Contingency 10%</td>
<td></td>
<td></td>
<td>$266.21</td>
<td>1</td>
<td></td>
<td>$187.60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>$2,928.31</td>
<td>1</td>
<td></td>
<td>$2,063.56</td>
</tr>
<tr>
<td>Mark up for profit, indirect cost</td>
<td>70%</td>
<td></td>
<td>$2,049.82</td>
<td>1</td>
<td></td>
<td>$1,444.50</td>
</tr>
<tr>
<td><strong>Net total manufacturing cost M/F</strong></td>
<td></td>
<td></td>
<td>$4,978.13</td>
<td>1</td>
<td></td>
<td>$3,508.06</td>
</tr>
<tr>
<td><strong>Net Total M/F, O &amp; M cost for 2 years</strong></td>
<td>=4798.13+</td>
<td>=8,486.19=</td>
<td>$4,243.10</td>
<td>1</td>
<td>8486.19/2 = 4243/(52weeks/yr x 5days/week) =</td>
<td>$16.32</td>
</tr>
</tbody>
</table>

Components and Sources of their cost

- **Water sprays**: [www.jirehtenterprise.com/id23.htm](http://www.jirehtenterprise.com/id23.htm)
- **Water Pressure hose 100' length**: [http://www.northerntool.com](http://www.northerntool.com). Search for Item# 30333
- **Water pump**: [http://www.northerntool.com](http://www.northerntool.com). Search for Item# 108295
- **Mark up for profit, indirect cost**: 70%
- **Over head costs considered 50 % of Labor**

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Chapter five explains the cost analysis and cost comparison of both water spray system and Vacuum system with prevalent methods adapted.
References


Cyclone fact sheet EPA 2003 Retrieved from
http://www.epa.gov/ttn/catc/dir1/fcyclon.pdf


Gambatese and James, 2001


Trencor literature Retrieved from www.trencor.com on August 30 2002


Chapter 5

RESULTS, COMPARISON AND ANALYSIS

This chapter tests and compares the feasibility of the two designed alternatives for dust control i.e. water-spray system and vacuum-based system using Micro CYCLONE simulation.

"Micro CYCLONE is a computer based simulation program designed specially for modeling and analyzing site level processes which are cyclic in nature. In broader terms, it can be used to model a construction operation, which involves the interaction of tasks with their related duration, and the resource unit flow routes through the work tasks are the basic rationale for the modeling of construction operations" (Retrieved September 28 2004 from http://cern.www.ecn.purdue.edu/CEM/Sirv/).

For example, the excavation process can be said to be of cyclic nature because of repeated sequence of activities performed. The excavation process can be divided into distinct work tasks performed in a logical order. Each work task takes a certain amount of time and resource to be completed. A graphical representation of the excavation operation can be constructed using the logical sequence, resources used, wait times, activity process time, delays observed in the field. By providing additional resources or suggesting installation of add-on
systems will reduce wait times and change the overall productivity. Using MicroCYCLONE this productivity can be evaluated.

The following discussion gives some more details about MicroCYCLONE followed by the modeling procedure, different simulation scenarios considered, site description, and a full-scale example of scenario #1.

5.1 MicroCYCLONE Simulation

"CYCLONE (CYCLic Operations NEtwork) simulation methodology was developed by Dr. Daniel W. Halpin to represent construction operations using software called MicroCYCLONE. It is a modeling technique that allows graphical representation and simulation of discrete systems dealing with deterministic or stochastic variables.

By changing initial conditions and resource specifications, different system responses result so that the user can select that mix of resources, work sequences, and technologies that best achieves his/her objectives. In this way, the user can experiment with the design of the construction operation and evaluate the economics and productivities of competing construction methods.”


5.1.1 Procedure for Modeling Excavation Operation

- Identify work tasks in the process
Processes like position Chain Trencher, spray water and excavate trench, return for refill water truck, etc., consume resources and time to perform excavation activity.

- Define resources

Equipment, manpower and material used to perform an operation are to be defined. For example, Chain Trenchers, water trucks, trench to be excavated are identified as resources.

- Determine the logic of the processing of resources

The different work tasks are arranged as per the logical sequence of an operation; for example, first the Chain Trencher aligns itself on the layout marked on the ground to be excavated, then the water truck tries to find a commanding position and begins to spray water on the possible sources of emission. Now the trencher can begin excavation.

- Build a model of the process

A graphical model can be built using the following notation

- Active State: Models a work task, and is represented in graphical notation as a square.
- Idle State: Models an entity waiting for processing, and is represented in graphical notation as a circle.
- Flow Direction: Models where resources flow after being processed. It is represented by a directional arc (arrow).
- Write the simulation program in Micro-cyclone code format.
The subsequent discussion comprises a full-scale example, site activity
description simulation scenarios, duration of activities, input file, trace run, and
sensitivity analysis results.

5.2 Detailed Site Activity Description

Following is a detailed site activity description for one of the two visited sites,
located near Mission Road and Horizon Ridge in Henderson, Nevada. The area
of the site was 284 ft x 700 ft. The property was to be divided into 15 single-
family residences and provided access by a cul-de-sac. The internal road
including shoulders was 44 ft wide. This site was taken as a sample site for
simulation purpose.

Figure 5.1 shows site to be trenched for utility lines for proposed residential
project. These utility lines shown in red lines in Figure 5.1 were 2 ft wide and 4 ft
deep. The Chain Trencher could begin excavation once the site is staked
(marked out) according to the offsite utility plan.

A Chain Trencher manufactured by 1460 HD Trencor was used on site for
excavating trenches. As per the Department of Air Quality Clark County
regulations, any trenching operation greater than 100 ft requires a water truck or
alternative arrangement to be used for dust control. One water truck per
equipment needs to be provided.

Each water truck on the job site had a capacity of 2000 gallons. Dust control
could be achieved by spraying water through the valve directly attached to water
truck or using a water hose. (Water hoses on a 2000 Gallon water tank are usually 50 ft long).

Figure 5.1
Site layout for simulation (Sketch drawn by author)

For simulation purpose the lots are numbered 1 through 15. For each lot, a utility trench to be dug was 100 ft long, 2 ft wide and 4 ft deep. The trenching operation
started once the Chain Trencher was aligned, and a water truck sprayed water onto the cutting edge of the trencher.

The cutting speed of Chain Trencher is dependant on several factors:

1. Type of soil encountered
2. Ambient moisture content
3. Type of equipment used
4. Width and depth of excavation
5. Accessibility
6. Skill of the operator

5.3 Duration Inputs

The following data and time interval readings recorded during the site visits were used for simulation:

- Position Trencher = 3 minutes
- Position water truck = 2 minutes
- Average excavation time per trench = 11 minutes
- Repositioning time for trencher = 3 minutes
- Repositioning time for water truck = 2 minutes
- Shifting time for hose connected to water truck = 1.5 minutes
- Capacity of water truck = 2000 gallons
- Length of water hose = 50 ft
- Dimensions of trench = 2 ft wide x 4 ft deep x 100 ft per lot
• Time required by water tank to empty ~ 44 to 45 minutes
• Time required for water truck to get a refill = 30 minutes

5.4 Different Simulation Scenarios

The different simulation scenarios explained here in detail are as follows:

1. Scenario # 1 One Chain Trencher and one water truck – base case.
2. Scenario # 2 One Chain Trencher and two water trucks – proposed alternative 1.
3. Scenario # 3 One Chain Trencher, one add-on system and one water truck proposed alternative 2.

At places where the time is of high priority or abundant equipment is available at low cost the number of resources can be increased from one trencher to two trenchers. Simulation scenarios were performed similar to the Scenario #'s 1, 2 and 3 with a few changes in resources, like the combination of two units of Chain Trenchers and water trucks:

4. Scenario # 4 Two Chain Trenchers and two water trucks – base case.
5. Scenario # 5 Two Chain Trenchers and three water trucks – proposed alternative 1.
6. Scenario # 6 Two Chain Trenchers and one water truck, and two add-on systems - proposed alternative 2.

5.4.1 Scenario # 1 One Chain Trencher and One Water Truck- Base Case

One Chain Trencher and one water truck combination was seen to be the most commonly used in the field to dig utility lines (like sewer lines, water lines
Excavation operation sequence began with the Chain Trencher taking the lead by aligning itself on the layout marked on ground.

Figure 5.2 shows the movement of the Chain Trencher and the water truck. A Chain Trencher (rectangle top left corner) excavates a trench shaded with light color to be excavated. The dark shaded rectangular line denotes an excavated trench and with a dark shaded line of berm on the right side of the rectangle. A schematic of the water truck in plan view and a water truck operator spraying water can be seen on the right hand side of the berm.

Figure 5.2

Plan (Top View) of movement of Chain Trencher and Water Truck
The Chain Trencher has to wait till the water truck operator aligns the water truck in a commanding position, so that water truck operator can spray water by a water hose or the nozzles mounted on the water truck body. As soon as the water truck operator is ready to spray water on to the central chain, the trencher can begin excavation. Once the pre-determined trench length is completely excavated, the Chain Trencher realigns itself onto the next trench and the water truck follows the lead of the Chain Trencher.
Figure 5.3

Scenario #1 - Simulation Diagram for One Chain Trencher and One Water Truck
This scenario is discussed later in Section 5.5 as a full scale example including: site description, activity description, activity durations, graphical representation, input file, trace run output showing logical sequence followed, productivity results obtained. Figure 5.3 gives the graphical representation of this scenario.

Each dot in Figure 5.3 at queue's 10, 20, 30, 40 denotes number of units of position available, water truck available, Chain Trencher available.

5.4.2 Scenario # 2 One Chain Trencher and Two Water Trucks – Proposed Alternative 1

During the site visits, it was observed that at the time when water truck made a trip to the stand tank for a refill, the Chain Trencher would stop working. Hence, adding one more water truck would minimize the wait time and the Chain Trencher could continue excavating trenches without a stop. The second water truck remains idle till first water truck has been emptied and has to return for a refill. The second water truck fills up the place of the first water truck. Thus the Chain Trencher can excavate non-stop.

Figure 5.4 shows the difference in simulation diagram. Queue 30 (water truck ready) has two dots representing two water trucks waiting for the Chain Trencher to position on the marked position on the ground.
Figure 5.4

Simulation Diagram for 1 Chain Trencher and 2 Water trucks

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Here Queue 30 shows two dots representing two water trucks. The results obtained by this scenario are shown in Table 5.5.

5.4.3 Scenario # 3 One Chain Trencher, One Add on System and One Water Truck - Proposed Alternative 2

A water spray system consisting of an on-equipment water tank, spraying water through water spray nozzles could act as a substitute for the water truck for a limited time. This on-equipment water tank needs to be refilled periodically by a water truck. The time when the on-equipment water tank has water, the water truck could be used for different purposes like spraying water on the site, removing mud tracks from the road, or getting a refill from a stand tank or a Jones valve.

The implementation of on-equipment water sprays would lead to less water consumption and higher productivity due to reduced wait times. The add-on water spray system installed on the Chain Trencher will have a water tank capacity of 320 gallons. Water spray systems attached to this water tank will spray water on the point sources of dust emissions.

The refill time for an on-equipment water tank is dependant on the water consumption by spray nozzles controlling dust at various point sources. This time interval can be determined as follows: \[\text{time} = 7 \times 1.1 \text{ gallons per minute per nozzle at a pressure of 40 psi} = 7.7 \text{ gallons per minute.}\]

Time required to empty tank = \[\frac{320 \text{ (gallons)}}{7.7 \text{ (gallons per minute)}} = 42 \text{ hour.}\]

This 42 minutes time is when the sprays remain on while the trencher is excavating trenches.
Figure 5.5 gets very simplified as compared to scenario #1 and scenario #2.

**Figure 5.5**

Simulation Diagram

1. Trencher 1
2. Water Truck 1
3. Add on

- 10 Water Truck Ready
- 20 Trencher Ready
- 30 Fill water in water truck on trencher
- 40 Trencher
- 50 Position available
- 60
- 70
- 80

- Reposition Trencher
- Spray water & excavate trench
5.5 Full Scale Example

5.5.1 Algorithm for Scenario #1- One Chain Trencher and One Water Truck

Clark County Best Management Practices (BMPs) require the use of dust control, usually a water truck per trencher excavating more than 100’ length of trench (Clark County website). A water truck of 2000-gallon capacity is accompanied by a Chain Trencher to control the dust emissions.

As per Figure 5.1, utility trenches for sewer line are to be dug by trenchers for lots 1 through 15. A Chain Trencher accompanied by a 2000-gallon water truck is used for excavation of trenches.

The simulation diagram showed in schematic (Figure 5.1) gives a logical sequence of the activities along these lines:

• Step 20 Trencher ready. At this position the Chain Trencher is ready for the job. Go to step 160.

• Step 160 Position trencher. Chain Trencher is aligned on the trench to be excavated. Go to step 60.

• Step 30 Water truck ready. A water truck filled with water is ready for spraying water. Go to step 50.

• Step 50 Position hose. Water truck operator unfolds water hose and aims water hose toward the cutting head of Chain Trencher. The length of water hose is usually 50’. Go to step 70.

• Step 60 Trencher ready for excavation. Go to step 130.

• Step 70 Hose ready. Water truck operator starts spraying water onto the cutting head. Go to step 130.
• Step 130 Spray water and excavate trench. Chain Trencher excavates trench while the water truck operator sprays water onto the cutting head, knocking down dust emissions. Go to steps 20, 90 and 140.

• Step 90 Function counter. This allows the program to set numbers of cycles and set a counter on completion of each cycle. Go to steps 100 and 110.

• Step 100 Reposition truck, as the trencher is repositioned (step 160) to next trench on next lot. Go to step 30.

• Step 110 con 4. This function of Micro cyclone allows water truck to refill and return once the tank is empty. Steps 30, 50, 70, 130 and 100 can be repeated four times to excavate trenches on lot 1, 2, 3 and 4. Go to step 120.

• Step 80 Water truck return and refill. After the water tank is empty, it has to move to a stand tank for refill and return to the location near the Chain Trencher. Chain Trencher cannot proceed until the water truck/water hose is used to spray water for dust control. Go to step 40.

• Step 140 con 4. This function of Micro cyclone allows trencher to be repositioned to the next nearest lot. Steps 20, 160, 60, 130 can be repeated four times to excavate trenches on lot 1, 2, 3 and 4. Go to step 150.

• Step 5 Reposition trencher lot to lot. Here Chain Trencher needs more time to be repositioned to next lot, as lot 5 is farther away from lot 4. Go to step 60.

Figure 5.3 gives a graphical representation for Scenario #1.

5.5.2 Input File for Scenario #1 - One Chain Trencher and One Water Truck

The Input File in MicroCYCLONE format is written in the following way:

NAME 'TRENCHER' LEN 8000 CYC 500
NETWORK INPUT
5 COMBI 'REPOSITION TRENCHER LOT TO LOT' SET 6 PRE 10 150 FOL 10
10 QUEUE 'POSITION AVAIL'
20 QUEUE 'TRENCHER READY'
30 QUEUE 'WATER TRUCK READY'
40 QUEUE 'POS AVAIL'
50 COMBI 'POSITION HOSE' SET 1 PRE 30 40 FOL 40 70
60 QUEUE 'TRENCHER READY'
70 QUEUE 'HOSE READY'
80 COMBI 'WATER TRUCK RETURN' SET 2 PRE 40 120 FOL 40
90 FUNCTION COUNTER FOL 100 110 QUA 1
100 NORMAL 'REPOSITION WATER TRUCK' SET 3 FOL 30
110 FUNCTION CON 4 FOL 120
120 QUEUE 'RETURN POSITION AVAIL'
130 COMBI 'SPRAY WATER & DIG' SET 4 PRE 60 70 FOL 20 90 140
140 FUNCTION CON 4 FOL 150
150 QUEUE 'TRENCHER WAIT'
160 COMBI 'POSITION TRENCHER' SET 5 PRE 10 20 FOL 10 60

DURATION INPUT
SET 1 1.5
SET 2 30
SET 3 1.5
SET 4 11
SET 5 3
SET 6 4

RESOURCE INPUT
1 'POSITION AVAILABLE' AT 10
1 'WATER TRUCK READY' AT 30 VAR 22.91 FIX 65.50
1 'POSITION AVAILABLE' AT 40
1 'TRENCHER READY' AT 20 VAR 26. FIX 423.75

ENDDATA

This input file was then compiled for any logical or typographical errors using the compile button. Then the simulation was run using the F5 button on the keyboard.

Cost inputs for the fixed and variable cost for water truck, Chain Trencher, Add-on water spray system are given in Table 5.1 and Table 5.2
### Table 5.1

**Fixed Cost for One Chain Trencher and One Water Truck**

<table>
<thead>
<tr>
<th></th>
<th>Qty</th>
<th>Cost / hour</th>
<th>Total cost / hour</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>One Chain Trencher and One Water Truck</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Structural Excavation of Trenches 8 feet deep</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fixed Cost</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Trencher</td>
<td>1.00</td>
<td>$330</td>
<td>$330</td>
</tr>
<tr>
<td>Vermeer Trencher weekly rental for model T 955</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$13,200</td>
<td>$2,640</td>
<td>$330</td>
</tr>
<tr>
<td></td>
<td>per week</td>
<td>per day</td>
<td>per hour</td>
</tr>
<tr>
<td></td>
<td>5 days/week and 8 hours per day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Water Truck</td>
<td>1.00</td>
<td>$37.50</td>
<td>$37.50</td>
</tr>
<tr>
<td>Hertz 2000 gallon rental</td>
<td></td>
<td>$300.00</td>
<td>per day</td>
</tr>
<tr>
<td>3 Labor Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite Field Crew</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator / Foreman</td>
<td></td>
<td>$65.00 per hour</td>
<td>1.00</td>
</tr>
<tr>
<td>Truck Operator</td>
<td></td>
<td>$28.00 per hour</td>
<td>1.00</td>
</tr>
<tr>
<td>Maintenance operator</td>
<td></td>
<td>$65.00 per hour</td>
<td>0.25</td>
</tr>
<tr>
<td>Replace worn Tungsten Bits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost / piece</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$10</td>
<td>$100</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td>$12.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$12.50</td>
</tr>
<tr>
<td><strong>Total Fixed Cost per hour</strong></td>
<td></td>
<td></td>
<td>$489.25</td>
</tr>
</tbody>
</table>

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Table 5.2

Variable Cost for One Chain Trencher and One Water Truck

<table>
<thead>
<tr>
<th></th>
<th>Variable cost One Chain Trencher and One Water Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trencher</strong></td>
<td></td>
</tr>
<tr>
<td>Fuel Cost</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>2.13</td>
</tr>
<tr>
<td><strong>Gal/ hr</strong></td>
<td><strong>$/ Gal</strong></td>
</tr>
<tr>
<td>$25.56</td>
<td>$25.56</td>
</tr>
<tr>
<td><strong>$/ hr</strong></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td></td>
</tr>
<tr>
<td>$7.50</td>
<td>8</td>
</tr>
<tr>
<td><strong>$/ day /8(hours/day)</strong></td>
<td><strong>$/ hr</strong></td>
</tr>
<tr>
<td>$0.94</td>
<td>$0.94</td>
</tr>
<tr>
<td><strong>Water Truck</strong></td>
<td></td>
</tr>
<tr>
<td>Fuel Cost</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.13</td>
</tr>
<tr>
<td><strong>Gal/ hr</strong></td>
<td><strong>$/ Gal</strong></td>
</tr>
<tr>
<td>$6.39</td>
<td>$6.39</td>
</tr>
<tr>
<td><strong>$/ hr</strong></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td></td>
</tr>
<tr>
<td>$1.00</td>
<td>8</td>
</tr>
<tr>
<td><strong>$/ day /8(hours/day)</strong></td>
<td><strong>$/ hr</strong></td>
</tr>
<tr>
<td>$0.13</td>
<td>$0.13</td>
</tr>
<tr>
<td><strong>Water Cost</strong></td>
<td></td>
</tr>
<tr>
<td>$20.49</td>
<td>$/1000 Gal</td>
</tr>
<tr>
<td>4000.00</td>
<td><strong>$/1000 Gal</strong></td>
</tr>
<tr>
<td><strong>GPD</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total Variable Cost per hour</strong></td>
<td><strong>$49.40</strong></td>
</tr>
</tbody>
</table>

Equipment operator rate obtained from:
http://www.or.blm.gov/vale/WhatWeDo/minerals/notice3-doc.pdf

Truck Operator rate obtained from:
http://www.dir.ca.gov/DLSR/PWD/Determinations%5CSouthern%5CSC-063-12-41.pdf

Water cost obtained from

Trencher rental rate obtained from Vermeer Sales Southwest, Las Vegas

Water Truck rate obtained from www.hertzequip.com
Gasoline price obtained from


Cost to replace worn Tungsten Bits

http://www.bussvc.wisc.edu/purch/contract/wp5240.html

Table 5.1 gives one cycle of trace run of the simulation. A trace run gives the
details of logical sequence followed per the program, simulation time instance,
activity name, number assigned in the input file and also states whether the
activity was combi (activity having two or more queues as predecessors) or a
normal (activity which does not have any queues as predecessors).

Referring to first row in Table 5.3 gives the first activity position trencher took 1.5
minutes to align, followed by another 1.5 minutes till the water hose was aligned.
The Chain Trencher begins excavation at 3 minutes and digs trench for 11 so the
fourth row shows a simulation time of 14 minutes.
Table 5.3

Trace run for simulation Scenario #1- One Chain Trencher and one Water Truck

<table>
<thead>
<tr>
<th>Simulation Time instance (Minutes)</th>
<th>Activity No.</th>
<th>Type</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>50</td>
<td>COMBI</td>
<td>POSITION TRENCHER</td>
</tr>
<tr>
<td>3</td>
<td>160</td>
<td>COMBI</td>
<td>POSITION HOSE</td>
</tr>
<tr>
<td>14</td>
<td>130</td>
<td>COMBI</td>
<td>SPRAY WATER &amp; DIG</td>
</tr>
<tr>
<td>14</td>
<td>90</td>
<td>COUNTER</td>
<td>-</td>
</tr>
<tr>
<td>15.5</td>
<td>100</td>
<td>NORMAL</td>
<td>REPOSITION WATER TRUCK</td>
</tr>
<tr>
<td>17</td>
<td>160</td>
<td>COMBI</td>
<td>POSITION TRENCHER</td>
</tr>
<tr>
<td>17</td>
<td>50</td>
<td>COMBI</td>
<td>POSITION HOSE</td>
</tr>
<tr>
<td>28</td>
<td>130</td>
<td>COMBI</td>
<td>SPRAY WATER &amp; DIG</td>
</tr>
<tr>
<td>28</td>
<td>90</td>
<td>COUNTER</td>
<td>-</td>
</tr>
<tr>
<td>29.5</td>
<td>100</td>
<td>NORMAL</td>
<td>REPOSITION WATER TRUCK</td>
</tr>
<tr>
<td>31</td>
<td>160</td>
<td>COMBI</td>
<td>POSITION TRENCHER</td>
</tr>
<tr>
<td>31</td>
<td>50</td>
<td>COMBI</td>
<td>POSITION HOSE</td>
</tr>
<tr>
<td>42</td>
<td>130</td>
<td>COMBI</td>
<td>SPRAY WATER &amp; DIG</td>
</tr>
<tr>
<td>42</td>
<td>90</td>
<td>COUNTER</td>
<td>-</td>
</tr>
<tr>
<td>43.5</td>
<td>100</td>
<td>NORMAL</td>
<td>REPOSITION WATER TRUCK</td>
</tr>
<tr>
<td>45</td>
<td>160</td>
<td>COMBI</td>
<td>POSITION TRENCHER</td>
</tr>
<tr>
<td>45</td>
<td>50</td>
<td>COMBI</td>
<td>POSITION HOSE</td>
</tr>
<tr>
<td>56</td>
<td>130</td>
<td>COMBI</td>
<td>SPRAY WATER &amp; DIG</td>
</tr>
<tr>
<td>56</td>
<td>90</td>
<td>COUNTER</td>
<td>-</td>
</tr>
<tr>
<td>56</td>
<td>140</td>
<td>CONSOLIDATE</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>5</td>
<td>COMBI</td>
<td>REPOSITION TRENCHER LOT TO LOT</td>
</tr>
<tr>
<td>86</td>
<td>80</td>
<td>COMBI</td>
<td>WATER TRUCK RETURN</td>
</tr>
<tr>
<td>87.5</td>
<td>50</td>
<td>COMBI</td>
<td>POSITION HOSE</td>
</tr>
<tr>
<td>98.5</td>
<td>130</td>
<td>COMBI</td>
<td>SPRAY WATER &amp; DIG</td>
</tr>
<tr>
<td>98.5</td>
<td>90</td>
<td>COUNTER</td>
<td>-</td>
</tr>
</tbody>
</table>
The counter hits one count. After repeating the cycle of digging four trenches the water tank is empty and needs a refill. Function consolidate diverts the water truck to (80 water truck) return to stand tank for a refill. The sensitivity analysis gives the result shown in Table 5.4

Table 5.4
Results of sensitivity analysis using Micro Cyclone for Scenario #1- One Chain Trencher and one water truck

<table>
<thead>
<tr>
<th>Resource Information</th>
<th>Productivity Information</th>
</tr>
</thead>
<tbody>
<tr>
<td># Of TRENCHER READY at TRENCHER READY</td>
<td># Of WATER TRUCK READY at WATER TRUCK READY</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Productivity Per Unit Time</td>
<td>Cost Per Unit Time</td>
</tr>
<tr>
<td>0.0475</td>
<td>8.1960</td>
</tr>
</tbody>
</table>

Table 5.5 gives the results obtained from a simulation using Micro CYCLONE For scenarios # 1 through # 6.
Table 5.5
Simulation results for different scenarios (water spray system as add-on)

<table>
<thead>
<tr>
<th>#</th>
<th>Scenario</th>
<th>Productivity Per Unit Time (cft/min)</th>
<th>Cost Per Unit Time ($/min)</th>
<th>Cost Per Prod. Unit ($/800cft)</th>
<th>Production 1 unit = 800cft (cft/min)</th>
<th>Cost/Production/unit time ($/cft/min)</th>
<th>Cost/Production/hour ($/cft/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1T 1WT</td>
<td>0.0475</td>
<td>$8.20</td>
<td>$172.53</td>
<td>38</td>
<td>$0.22</td>
<td>$12.94</td>
</tr>
<tr>
<td>2</td>
<td>1T 2WT</td>
<td>0.0714</td>
<td>$9.27</td>
<td>$129.81</td>
<td>57.12</td>
<td>$0.16</td>
<td>$9.74</td>
</tr>
<tr>
<td>3</td>
<td>1T 1WT 1 ADD ON</td>
<td>0.0904</td>
<td>$8.50</td>
<td>$94.14</td>
<td>72.32</td>
<td>$0.12</td>
<td>$7.05</td>
</tr>
<tr>
<td>4</td>
<td>2T 2WT</td>
<td>0.0711</td>
<td>$32.27</td>
<td>$454.18</td>
<td>56.88</td>
<td>$0.57</td>
<td>$34.04</td>
</tr>
<tr>
<td>5</td>
<td>2T 3WT</td>
<td>0.0882</td>
<td>$38.27</td>
<td>$434.06</td>
<td>70.56</td>
<td>$0.54</td>
<td>$32.54</td>
</tr>
<tr>
<td>6</td>
<td>2T 1WT 2 ADD ON</td>
<td>0.0904</td>
<td>$27.96</td>
<td>$309.37</td>
<td>72.32</td>
<td>$0.39</td>
<td>$23.20</td>
</tr>
</tbody>
</table>

T = TRENCHER

WT = Water Truck

ADD ON = add on water spray system.

Comparing scenario # 3 (1T 1WT 1 ADD ON) to scenario # 1(1T 1WT), it can be seen that there is a definite increase in the productivity per unit time. More soil can be excavated in unit time in Scenario 3, the cost per productivity per unit goes down from $172.53 to $94.14 (83.26% savings).

Scenario # 1 has a productivity of 0.0475 units per minute (one unit is 800 cubic feet of soil excavated), in the same amount of time Scenario # 3 excavates...
0.0904 units per minute. Total production quantity of each scenario is obtained by multiplication of (productivity /unit time) with {1 unit (800 cft of soil excavated)}.

Scenario # 2 (1T 2 WT) formed by adding an additional truck as a standby to the base case {Scenario# 1 (1T 1WT)}, improves the productivity by 33% and the cost per production per hour goes down by 33%. The wait times are reduced as the stand by truck replaces the empty water truck, and work can go non-stop. An additional water truck would be beneficial in terms of getting higher productivity.

5.6 Sample Site Activity Description for Road Miner and Water Truck Combination

The second site visited was located at Sunrise Colony Company, Sienna, off 215 and Tropicana Avenue, Las Vegas, Nevada. A Trencor Road Miner model 1260 HD, accompanied by a 2000 gallon capacity water tank, was seen performing an excavation operation for the sub grade of a golf cart drive way and a 20 foot wide access road. A Road Miner 1260 HD can excavate 12.66' wide and 2'deep road in one pass.

Figure 5.6 show the west side of the site was already landscaped. Location 1 in Figure 5.6 shows the location of a proposed golf cart driveway.
The Road Miner was seen excavating the sub grade, aligned perpendicular to the golf cart driveway at location 1, where as, on location 2 the Road Miner was aligned to be parallel to the 20' road to be excavated for sub grade.

Simulation scenarios for a combination of Road Miner, water truck, and or add on dust control system were performed considering observed alignment of the Road Miner with respect to the proposed road to be excavated as follows:

- Road Miner excavating parallel shown in Figure 5.8 and
- Road Miner excavating perpendicular shown in Figure 5.10
5.6.1 Scenario # 7 One Road Miner and One Water Truck (Aligned Parallel to the Road Miner) – Base Case

Here the Road Miner makes two passes. In pass 1 (Figure 5.7) the Road Miner excavates half width of road and then makes a second pass. Pass 2 covers remaining half of the road width overlapping the first run by a couple of feet.

Figure 5.7

Road Miner operating in parallel position

As per Clark County Best Management Practices water truck or other dust control measure needs to be adopted to lower the emissions from the excavation operation. The water truck moves simultaneously with the Road Miner and sprays water onto Road Miner cutting head through one of the front sprinklers.
Simulation scenarios were performed for a combination of Road Miner water truck and add-on system. These scenarios are as follows:

1. Scenario # 7 One Road Miner and One water truck (aligned perpendicular to the Road Miner) – base case.
2. Scenario # 8 One Road Miner and two water trucks (aligned perpendicular to the Road Miner) – proposed alternative 1.
3. Scenario # 9 One Road Miner, one add-on system and one water truck—proposed alternative 2.
4. Scenario # 10 One Road Miner and one water truck (aligned parallel to the Road Miner) – base case.
5. Scenario # 11 One Road Miner and two water trucks (aligned perpendicular to the Road Miner) – proposed alternative 1.
6. Scenario # 12 One Road Miner, one add-on system and one water truck—proposed alternative 2.

5.6.1.1 Algorithm for Simulation Diagram of Road Miner Operating in Parallel position.

- Step 5 Road Miner ready to excavate.
- Step 10 Position Road Miner. Road Miner operator aligns Road Miner and waits for water truck to start spraying water onto the cutting face.
- Step 60, 70, 80 Water truck gets ready and it aligns itself so as to get good commanding position to spray water. Water truck operator now sprays water from one of the front side sprinklers.
- Step 40 Excavate. Road Miner begins excavation.
• Step 90 After excavation for 30 minutes the water truck needs refill. Road Miner stops operation till the water truck gets a refill.

• Step 110 Water truck is repositioned and ready to spray water on cutting face of Road Miner.

This continues till a 100' x 20' x 2' deep road sub grade has been excavated.

Figure 5.8 gives the graphical representation one Road Miner Operating Parallel with one water truck.
Figure 5.8
Simulation Diagram for one Road Miner Operating Parallel with one Water truck

[Diagram showing the sequence of operations involving a Road Miner and a Water truck, with numbered positions and actions such as 'Position Available', 'Reposition Roadminer', 'Excavate', 'Water Truck ready', 'Reposition Water truck', 'Water truck refill and return', and 'Con 2'.]
5.6.1.2 Scenario # 8 One Road Miner and Two Water Trucks (Aligned Perpendicular to the Road Miner) – Proposed Alternative 1

Similar to the Simulation Scenario # 2 two Chain Trenchers and two water trucks, an additional water truck could be deployed to the base case for one Road Miner and one water truck- base case.

This additional truck remains idle till the first water truck is empty, as soon as the first water truck returns for get a refill from a on site water source, the second water truck fills up the void of the first water truck and excavation can proceed non-stop with out violating Clark County Best Management Practices for Air Quality.

Figure 5.9 gives the Simulation Diagram for one Road Miner Operating parallel with two water trucks. Queue 90 shows two dots representing two water trucks.
Figure 5.9
Simulation diagram for one Road Miner operating parallel with two water trucks
Scenario # 9 One Road Miner, one add-on system and one water truck—proposed alternative 2 is very similar to Scenario # 3 One Chain Trencher, one add-on system and one water truck—proposed alternative 2. To prevent the repetition of almost same scenarios the discussion has been eliminated.

5.6.2 Scenario # 10 One Road Miner and One Water Truck (Aligned Perpendicular to the Road) – Base Case

Figure 5.10 shows plan view of mode of excavation for Road Miner excavating sub grade perpendicular to road. The Road Miner cuts 12.66’ wide * 2’ deep at one time.

Road Miner makes first pass perpendicular to road cutting at 12.66’ wide, then realigns it self to position immediately adjacent to first pass. The Road Miner has to make about eight cycles to cut a 100’ long road 20’ wide. Each pass Road Miner excavates for four minutes and takes 1.5 minutes to reposition Road Miner and water truck at each pass.
While the Road Miner cuts 100' long road 12.66' wide for 30 minutes, a 2000 gallon water truck after 30 minutes of spraying has to leave back for refill from a stand tank. Road Miner waits till water truck arrives back with refill and starts spraying on cutting face. The Road Miner then excavates the remaining half of the road (100' long 7.33' wide).

5.6.2.1 Algorithm for Scenario # 10 One Road Miner and One Water Truck (Aligned Perpendicular to the Road) – Base Case

Simulation diagram shows the following sequence for Road Miner operating in perpendicular position.
• Step 5 Road Miner ready to position itself.
• Step 10 Position Road Miner perpendicular to road at far end of the road.
• Step 40 Once water truck and Road Miner are aligned and water truck begins spraying water on cutting face of Road Miner, Road Miner begins excavation.
• Step 50 Road Miner operator repositions Road Miner beside first pass.
• Step 70 Water truck operator repositions water truck according to Road Miner.
• Step 40 is repeated till water truck is empty.
• Step 90 The water truck has to refill and return after about 30 minutes of excavation operation.

Repeat steps 5, 10, 70, 40, 50 till about 100' of road is excavated.
Figure 5.11
Simulation Diagram for One Road Miner with add-on Dust Control and a Water Truck Operating Parallel
Table 5.6
Simulation results for Scenarios # 7 through # 12 Road Miner

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Productivity Information for Road Miner Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Productivity Time Per Unit</td>
</tr>
<tr>
<td></td>
<td>(cft/min)</td>
</tr>
<tr>
<td>1RM 1WT perpendicular</td>
<td>0.063</td>
</tr>
<tr>
<td>1RM 2WT perpendicular</td>
<td>0.0699</td>
</tr>
<tr>
<td>1RM 1WT ADD ON perpendicular</td>
<td>0.2462</td>
</tr>
<tr>
<td>1RM 1 VACUUM ADD-ON System</td>
<td>$0.1821</td>
</tr>
<tr>
<td>1RM 1WT Parallel</td>
<td>0.1112</td>
</tr>
<tr>
<td>1RM 2WT Parallel</td>
<td>0.1538</td>
</tr>
<tr>
<td>1RM 1WT ADD ON Parallel</td>
<td>0.4262</td>
</tr>
<tr>
<td>1RM 1 VACUUM ADD-ON System</td>
<td>0.312</td>
</tr>
</tbody>
</table>

RM = Road Miner, WT= Water truck, 1 = One (Equipment), 2 = Two (Equipments)

Comparing Scenario #’s 7, 8, 9 with Scenario #’s 10, 11 and 12 indicates that the Road Miner excavates parallel to the road gives higher productivity, excavating more cubic yard of earthwork at less cost. Also, predicted productivity with the add-on spray system (Scenario #’s 9 and 12) is much higher.
than without the add-on. The result is that predicted costs per unit of production are considerably lower for the add-on vacuum system and add-on water spray system scenarios.

5.7 Vacuum System Operational Cost

Implementing a successful vacuum dust control system on a Road Miner or a Chain Trencher will eliminate use of water truck, water truck operator, and any attached variables related to water truck. The Road Miner or Chain Trencher could operate without any delays or work stoppages caused due to water truck.

The implementation cost of a vacuum system is estimated to be $20,048.60. The incremental daily cost for vacuum system would be = $20,048.60/52 weeks/5 days per week/8 hours per day = $9.63 per hour for the add-on system. All the costs associated with the water truck, such as rental cost, cost of operator, and fuel and maintenance cost, could be eliminated.

Comparing the operational costs of one Road Miner with a vacuum add on system to the base case scenario of one Road Miner and one water truck, the production (amount of soil excavated) per day would be = productivity/ day * # cubic yards per unit. One unit for the Road Miner = 19' wide * 3' deep * 50 feet long = 2850 cft / 27 (cu.yd / cft ) = 105.55 cu. yd.

Production per day for base case of one Road Miner and one water truck is 3192 cu yd./day and the cost per day of operating equipments per day (8 hour /day) = $6427.
Production per day for one Road Miner and add on vacuum system is 9226 cu yd./day and the cost per day of operating equipments per day (8 hour/day) = $4041.60.

Comparing the savings a combination of Road miner and an add-on vacuum system would excavate 6034 cu. yd more than the base case scenario. The cost / production in a day would be = (cost/day) / (production/day) = $4041.60 / 9226 cu yd. = $0.438, the same cost for that of a one Road Miner and one water truck is $2.014. Savings per day = amount of production/day * cost savings per production = 9226 - 3192. * savings (2.014- 0.438) = 6034 cu. yd * $1.58 = $ 9,507.12 . The estimated installation cost for the system is $23,992.

The pay back period = system cost/ savings per day = $23,992/$9,507.12 = 2.52 days. This pay back period is based on the simulation scenario costs, and can be applicable to areas like Clark County where the Air quality regulation are strict, requiring the use of dust control on heavy equipments while performing an excavation operation.

Pay back period for the water spray system on a chain trencher comes out to 17.49 days.

The production for base case of one chain trencher and one water truck = 675.55 cu. yd./day. The unit considered in for simulation is 2’ wide trench * 4’ deep trench * 100’ long trench = 800 cft = 800 cft/ 27 (cu.yd / cft ) = 29.63 cu. yd.

Production /day = 0.0475 prod/min * 60 min * 8 hours /day = 675.55 cu. yd./day. Cost / production for one day = (cost / day) / (production/ day) = $ 5.823/ cu. yd for a day. The cost/ production for water spray system comes out to $4.02/ cu. yd.
yd for a day. Amount saved = 339.9 cu yd (excavated more) * $1.81 (savings per day) = $613.75. Capital investment cost = $8,486.

Payback period = $8486 / $613.75 = 13.83 say 14 days.

5.8 Comparison of Water Spray and Vacuum Design

- Adaptability:

Vacuum design for a Road Miner requires hoods and shrouds to contain and convey dusty air stream to the ducting. Most of the Chain Trenchers have a boom but no shrouds, surrounding the cutting head. An extra cost will have to be incurred to enclose the boom chain. Hence vacuum system can be adapted for Road Miner, but would not be as cost efficient and effective for a Chain Trencher.

- Parasitic Power Demand:

Vacuum and Water spray systems are not in built systems but are added on to the equipment. Therefore any power they would use from the equipment can be called as parasitic power demand.

Parasitic power demand for the vacuum system for Road Miner 1660HD is @ 6.59 Horsepower (Hp) and that for water spray system is ½ Hp. Road Miner is rated for 746 Brake horse power (BHp), even at peak demand the equipment was using 50% of power. Vacuum system can well be adapted if the manufacturer backs up 6.5 Hp of power demand. Comparatively, water spray system tends to be superior because of low power requirements.

- Residue:

Vacuum system has a dust collector that sifts the dusty air stream into dust
and clear air stream with very few PM$_{10}$. The collection chamber (cyclone) collects and leaves behind fine PM$_{10}$ dust, which has to be disposed off at intervals.

Water spray system knocks down dust at source and leaves behind wet dust particles in the excavated soil itself.

- **Weight of System:**

Water spray system requires water tank of approximately 320 gallon tanks. PVC tank filled with water will weigh approximately 2800 lbs (weight of water 8.34 lb/gallon). Operating weight of Road Miner 1260HD is 125000 lbs. Care has to be taken to balance the weight to prevent any operational hindrances (possibility of tipping the equipment over).

For the vacuum system, weight should not exceed 100 lbs.

- **Water Truck Requirement:**

At present equipments like Road Miner or Chain Trencher require a dedicated water truck as per recommendations of Clark County Best Management Practices (CCBMP).

Vacuum design would eliminate water truck requirement, thus saving cost of one water truck and one water truck operator. If a water spray system is adapted to Road Miner or Chain Trencher, one water truck can work as a server, refilling several on-equipment water tanks as and when needed. For example, if there are several Road Miners or Chain Trenchers on a job site, add-on water spray system will prevent deployment of dedicated water truck and water truck operator.
per equipment and could work as one water truck refilling several equipments as and when needed.

Vacuum system, if fully functional, will eliminate the use of water truck and water truck operator.

• Cost:

Cost comparison shows that a Vacuum system would cost initially about $20,048.60 and the water spray system about $8,486.20 (Chapter 4 gives the cost for water spray system and vacuum system).

The incremental daily cost for vacuum system would be = $20,048.60/52 weeks/5 days per week/8 hours per day = $9.63 per hour for the add-on system. All the costs associated with the water truck, such as rental cost, cost of operator, and fuel and maintenance cost, could be eliminated.

Table 5.6 gives the cost of excavation using vacuum system as an add-on system.

• Maintenance:

Vacuum system has several moving parts (fans, blowers, ducting etc) which are susceptible to wear and tear by rough handling and impact of dust particles. Spray nozzles may get clogged and require frequent cleaning. Adapting bigger size of spray nozzles could easily eliminate this problem. Spray nozzles should be carefully placed away from the impact of flying dust particles.

The following chapter gives the summary of design, the recommendation about an add-on system to be implemented, and recommendations related to further research.
References

Micro Cyclone simulation retrieved and adapted on June 8th 2004 from
http://ce.ecn.purdue.edu/CEM/Sim/.
CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This thesis research evaluated the potential cost effectiveness of alternative methods of dust control on a Chain Trencher and Road Miner as an effort to comply with local & national ambient standards for dust emission.

The cost comparison obtained from MicroCYCLONE® simulations clearly shows cost savings associated with on-equipment dust control can be achieved by improving productivity and reducing wait times. The add-on systems definitely will cut down cost per cubic foot of excavation.

6.1 Recommendation for Add on System for Trencor Chain Trencher

From the preliminary design, cost and feasibility analysis in the earlier chapter we recommend a water spray-based system for a Chain Trencher. This recommendation is justified by the following reasons:

- Easy installation
- Lower initial and maintenance cost
- Readily available materials
- Better adaptability; most of the parts can be easily retrofitted. The design can be adapted and changed as per different model numbers to match the configuration, geometry and dimensions of the equipment.

- Low parasitic power demand

- In the water spray system dust is knocked down at the source.

- A Vacuum system on a Chain Trencher would need require additional initial cost for the hood or shroud to enclose the cutting chain. In addition, the shrouds around the boom of the Chain Trencher might hamper the operational capabilities of Chain Trencher.

6.2 Recommendation for Add on System for Trencor Road Miner

A vacuum based system is recommended for a Road Miner. This recommendation is justified by the following reasons:

- Lower operating cost

- The high initial cost can be offset by elimination of the water truck, water truck operator and any associated operation & maintenance cost for the water truck.

- Adaptability: unlike Chain Trencher, the Road Miner has shrouds over the cutting face, so hoods can be easily adapted to be mounted on these existing shrouds.
6.3 Future Research and Recommendations

This preliminary design and cost analysis could be used to justify development of prototype on-equipment dust control systems for two types of heavy construction equipment and can be presented to construction industry for their consideration. This preliminary design can be installed as a prototype on one Chain Trencher or Road Miner and put to a pilot test. Results of the pilot test could be used to refine the design.

On successful implementation, the design can be incorporated in a computer program so as to get a standardized design for any Chain Trencher or Road Miner model.

Further research can be continued for other heavy construction equipment, such as aggregate crusher, rock saws, surface miners, wheel loaders, etc by:

- Characterizing dust emissions
- Identifying specific dust-generating sources
- Preliminary design of dust control equipment and cost benefit analysis
- Prototype testing,
- If successful, Implementation

This thesis demonstrates strong potential for construction industry to improve productivity and reduce wait times, while complying with local regional and national air quality standards. There are also potential benefits for reducing occupational exposure to dusts.

Thus on-equipment dust control represents one step towards a cleaner environment that includes better occupational safety and reduced pollution.
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