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Paper

THE USE OF HIGH PRESSURE WATERJETS TO IMPROVE PERFORMANCE OF ROTARY CUTTER HEAD DREDGES FROM THE INSIDE OUT

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ABSTRACT

Current cutter head dredges utilize the rotational motion of the cutter head to size and move the material towards the dredge suction inlet. This paper examines the possibility of using waterjets and cavitation in conjunction with a conventional mechanical cutter head and how it improves excavation efficiencies and material recoveries, while reducing the environmental impacts associated with sediment loss and pollution.

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1.0 INTRODUCTION

Dredging systems have been utilized for many years both in the civil construction and mining industries. One of the earliest descriptions of a dredge was in 1372, when M. Le Demour sent the description of a novel type of pumping system to the French Academy[1]. The first reported use of a dredge for ore production was in 1565 in the lowlands of Europe[2]. Subsequent developments in mineral dredging technology have tended to follow one of three methods: mechanical dredging, hydraulic suction dredging, or a combination of mechanical and hydraulic suction dredging methods. While all three methods have improved over time, they still suffer the following limitations: bottom losses, when material is disturbed by the dredge but not excavated and falls to the bottom of the water column; material blockages, when oversize or near oversize material blocks or partially obstructs the dredging mechanism; and inefficiencies associated with oversizing equipment to compensate for these issues, increasing costs while still suffering some of the aforementioned limitations.

To overcome these problems, it is proposed that, by using cavitating waterjets in conjunction with a standard mechanical-based dredge, these limitations may be reduced. The following background information describes the basic dredging methods and their limitations, and is intended to serve as a basis as to why the proposed technology may be a vast improvement over the current conventional dredging techniques.

2.0 BACKGROUND

Dredging methods can be categorized by the technology employed. There are three basic technologies employed in dredging systems:

1) Hydraulic,
2) Mechanical, or,
3) Combination systems utilizing both mechanical and hydraulic elements.

2.1 Hydraulic Suction Dredge Systems

Hydraulic suction dredging represents one of the simplest types of dredging systems, consisting primarily of a pump and suction pipe. The suction tube is positioned in a well between the pontoon bows to which it is hinged. The other end of the suction pipe is suspended from a gantry or A-frame by a ladder hoist. The ladder hoist is connected to a winching system in order to suspend the suction pipe at the desired depth. **Figure 1** shows a typical plain suction dredge system. Suction dredges may also employ a waterjet near the suction intake. The stream of water is used to loosen the material aiding in the dredging process. A typical waterjet installation can be seen above the suction inlet in the left side picture in **Figure 1**.

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[1]Macdonald Eoin H., Alluvial Mining: The geology, technology and economics of placers. 1983
[2]Dekker, P.M., Dredging and Dredging Appliances. 1927

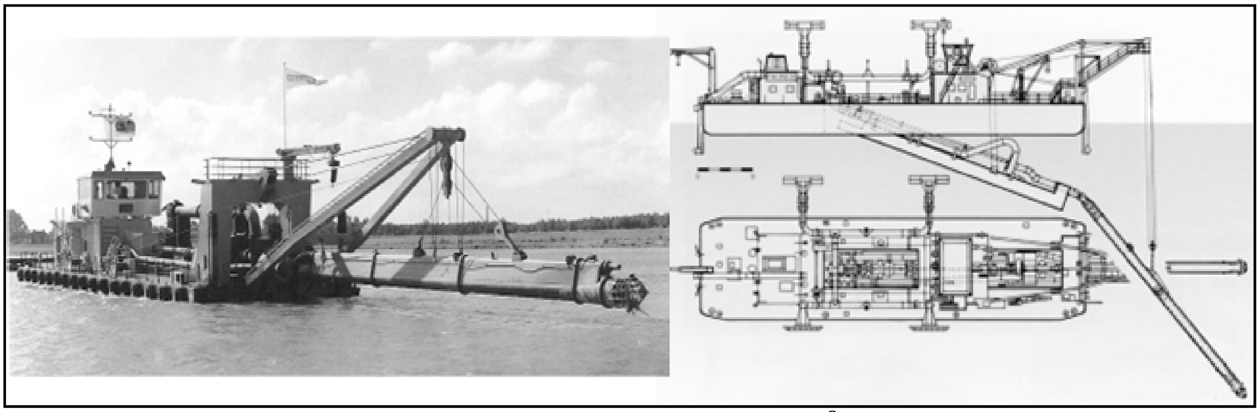


Figure 1. Plain Suction Dredger[3]

Excavation of material is by the erosion of a jet stream and/or the suction flow of the dredge pump and the breaching process[3] (**Figure 2**).

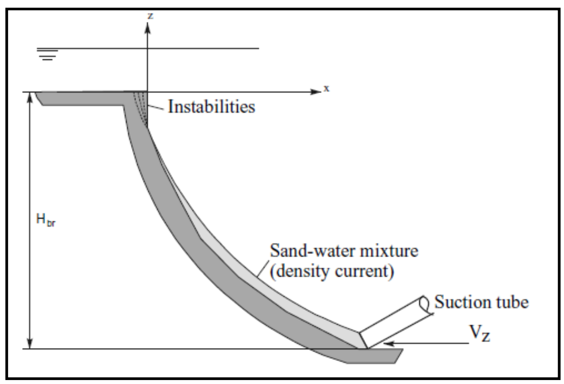


Figure 2. Breaching Process Angled Suction Typical of Dredging[3]

Plain suction dredges are only used to extract non-cohesive material that can be loosened near the suction mouth by the use of eddies created in the flow of water going into the suction pipe. As a result, hydraulic dredge systems have substantial difficulties when they encounter "hardpan" (a cemented or compacted layer of material), rocks, and other solid geologic material interspersed within the material to be excavated. The solid material may either be too heavy to be entrained in the suction stream or of such size that it blocks or partially obstructs the suction pipe or pump. To overcome these situations, some hydraulic dredging systems employ waterjets to loosen/break up the material allowing the suction stream to pull the components into the suction pipe. When the jet is run parallel to the suction pipe, the resulting debris plume may escape suction and will result in increased losses and low-density (tonnage) slurry production. **Figure 3** shows two different hydraulic dredge systems utilizing waterjets.

[3]Vlasblom W.J., Designing Dredging Equipment, Chapter 4 – Plain Suction Dredgers – 2003

Hydraulic Suction Dredge with parallel water jet system

Hydraulic Suction Dredge with rotating water jet system

Figure 3. Hydraulic Suction Dredge Systems and Waterjets[3]

Moreover, due to the limited types of material that they are capable of excavating (non-cohesive) and the breaching method employed, these dredge systems are not suitable for selective extraction work such as the excavation of specified profiles.

2.2 Mechanical (Bucket Line) Dredge Systems

The method most commonly associated with mining is the bucket elevator dredge first developed in New Zealand in the 1860s, with derivations occurring in Montana and California within a couple of decades. These dredges employ a series of buckets to mechanically remove gravels, sands, and soils (**Figure 4**)[4]. They are not capable of digging through solid rock or transporting rocks bigger than their buckets. The digging depth of these dredges is limited by the size of the bucket ladder and the required horsepower and support structure needed to operate the bucket line. They also may suffer significant losses as material, once loosened, may not fall within the bucket and end up either on the bottom, or in the case of fine sediments and clays, floating in the water, creating a potential pollution problem. These types of dredges, while still in use, are falling out of favor due to environmental considerations and inefficiencies compared to other dredges. However, they continue to operate in developing jurisdictions as well as historic areas of operation where they have permits. **Figure 4**, shows Mineros's dredge #3 and its bucket ladder[5]. Note the turbidity of the water adjacent to the buckets. The dredge recently underwent 5 years of repairs (starting in 2005) allowing the dredge to operate to a depth of 26 meters. This is only 1 meter deeper than before refurbishment. Of the 1,268 registered dredges in the Dredgers of the World Vessel Register 7th Edition (2009-2010), only 53 were bucket ladder dredges, most of which were built decades ago.

[4] Spidy E.T. Alluvial Gold, The New Zealand Railways Magazine, Volume 13, Issue 1 April 1, 1938 p 49
[5] Grayson R. Bucket-line gold dredges – a review of world techniques, World Placer Journal – 2008

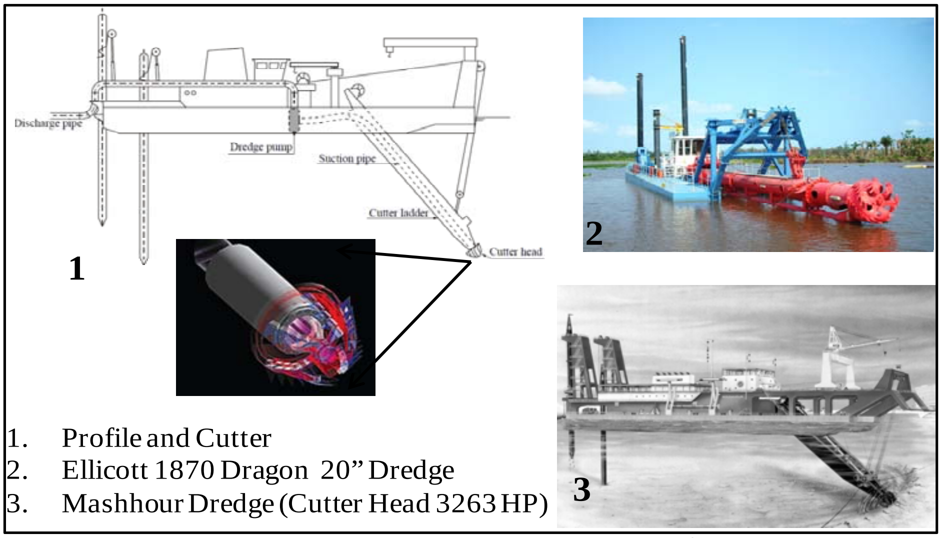
Figure 4. Bucket Line Dredges Then and Now[4,5]

Other means of mechanical dredging are primarily used for civil works. They are essentially a dragline or hydraulic excavator mounted on a barge. These mechanical dredging systems do not generate the volume/tonnage of excavated material typically required for mining operations and suffer from the same limitations (digging depth, material losses, and fine sediment pollution) as bucket line dredges.

2.3 Combination Dredge Systems

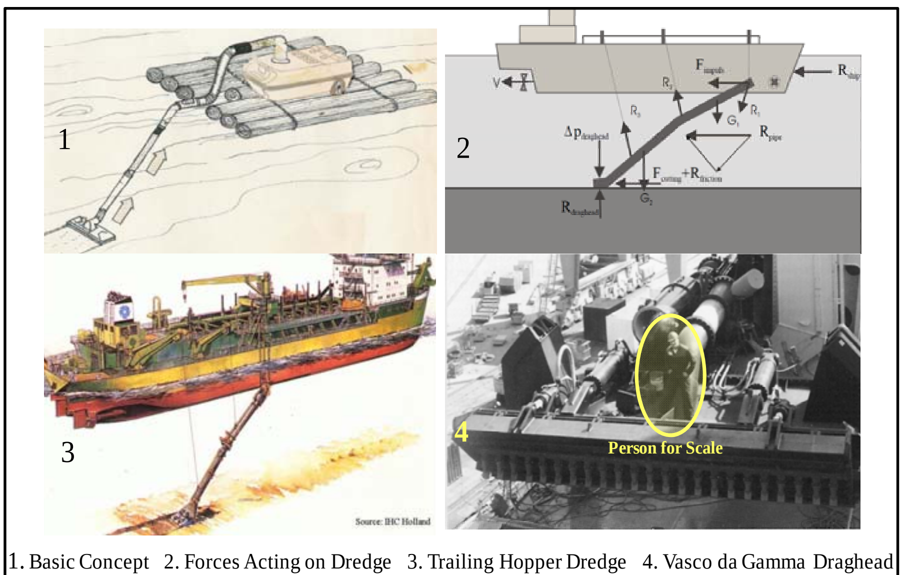
The most common form of commercial dredging equipment involves a combination of mechanical and hydraulic systems. These systems make up approximately 70% of the world's commercial dredge fleet[6]. These systems can be further subdivided into active (cutter suction) and passive mechanical systems (trailer suction), these dredges comprise 32% and 38% of the commercial dredge fleet, respectively. While similar in principal, these types of dredge systems differ substantially in how the mechanical forces are deployed. Active systems apply mechanical force near the suction by actively rotating or turning a cutting wheel while passive systems apply mechanical force by pulling a drag head in a manner similar to pulling a vacuum. Both forms of dredging utilize mechanical energy to excavate and move the dredge material into the influence of the high velocity water near the suction intake. **Figures 5** and **6** show examples of these two types of dredging systems.

[6]Dredgers of the World Vessel Register 7th Edition (2009-2010) CRSL



1. Profile and Cutter
2. Ellicott 1870 Dragon 20" Dredge
3. Mashhour Dredge (Cutter Head 3263 HP)

Figure 5. Cutter Suction Dredges[7,8]



1. Basic Concept 2. Forces Acting on Dredge 3. Trailing Hopper Dredge 4. Vasco da Gamma Draghead

Figure 6. Drag Head Dredges[9,10]

2.3.1 Trailer Suction Dredges

Trailer suction dredges are currently the most popular type of commercial dredging systems. The first trailer suction dredge was the General Moultry built in 1855 in the United States[9]. Since the 1950s, their use has increased steadily as ships and channel depths have increased. In additon, these dredges work while moving, presenting less of an obstacle when dredging an active ship channel. Another of the primary reasons for their popularity has been the recent inclusion of

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[7] Ellicott Dredge 2011 product brochure
[8] Vlasblom W.J. WB3408b Designing Dredging Equipment, Chapter 3 – Cutter Suction Dredger, May 2003
[9] Vlasblom W.J. WB3408B Designing Dredging Equipment Chapter 2 Trailing Suction Hopper Dredger, May 2005
[10] Vlasblom W.J. Designing Dredging Equipment OE4671/WB3408 Delft University of Technology September 2006

waterjets on the drag head allowing the dredges to excavate material faster and with less ship horsepower. Prior to the use of waterjets, all the force generated was the result of mechanical transfer from the ship to the drag head to the material. Excavating at depth meant the ship size and horsepower would have to increase in order to move the drag head and support structure and to overcome the effects of the increased water pressure. The increased pressure compacts the material making it behave more like a solid, requiring even more force to loosen it for dredging.

The use of waterjets on drag heads lessens the effects of the water pressure and the need to transfer force from the ship to the drag head. Waterjets are deployed adjacent to or in the hollow teeth of the trailer head. They inject water into the material to be dredged increasing the pore space between the particles. The densely packed fine sands and clays expand, offsetting the effect of increased water pressure and resulting compaction, allowing the material to be dredged as if it were free flowing sand.

Traditional strategies to improve the production of drag heads normally focus on increasing the jet pump power and the weight of the drag head[11]. **Figure 7** shows the basic components of a drag head with waterjet assistance.

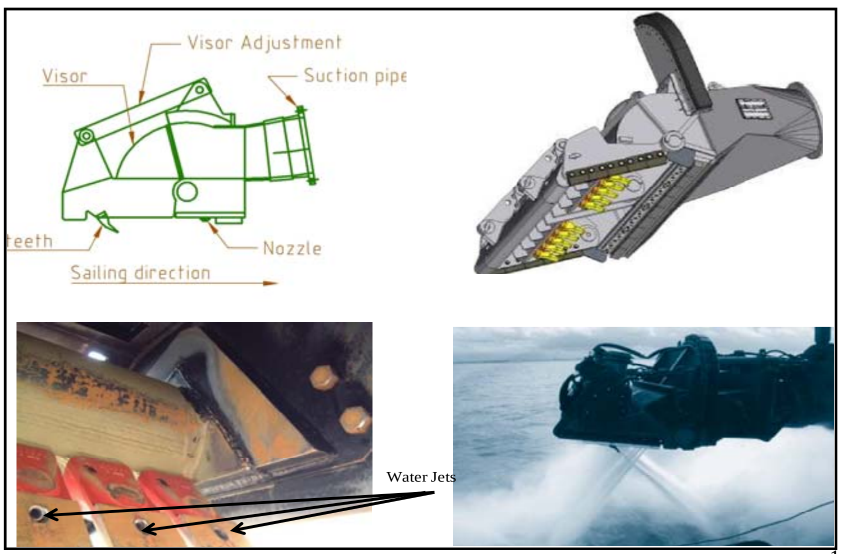

Figure 7. Waterjet Assisted Drag Head Components and Pictures[11]

Trailer suction dredge systems have limited applicability, as they need to be towed by a ship of sufficient size and horsepower to pull the drag head forward; this in turn limits their use to larger bodies of water. Trailer suction dredges are not anchored and can only apply force to the material to be excavated through the weight of the equipment, the force applied by the ship's motion, and the impingement of the waterjets. This limits their ability to dig hard and conglomerated materials as they cannot apply sufficient force to liberate the material for dredging. In addition, because the drag head is towed, it makes maneuvering and placement difficult. As a consequence, the excavation of irregular patterns or contouring associated with topography is extremely problematic, further reducing the applicability of the system in many mining applications.

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[11]Van de Velde, Marc Wild dragon® birth of a concept 2007. http://www.theartofdredging.com/wilddragon.htm

2.3.2 Cutter Suction Dredges

The other combination method of dredging also utilizes mechanical methods to liberate the material and in some cases, move it toward the suction intake. These systems differ from trailer dredges in that they transfer force from a mechanical cutter head assembly directly to the material instead of transferring force from a moving ship. Once liberated, the material is drawn into the suction pipe in the same manner as a hydraulic dredge. The cutter head is responsible for the actual excavation of the soil. There are two primary types of cutter suction dredges: rotary or basket cutters and bucket wheels.

The rotary or basket cutter dredge utilizes a cone (basket) shaped cutter head usually configured with six blades. The cutter head excavates and mixes the material with water moving it towards the suction inlet. The cutter head and drive are mounted on the end of the suction ladder. This ladder provides the weight on the cutter head to ensure that the teeth on the cutter head have sufficient thrusting force to penetrate the soil. The ladder can be lowered in order to cut at different depths. **Figure 8** illustrates the relevant parts of a typical cutter suction dredge.

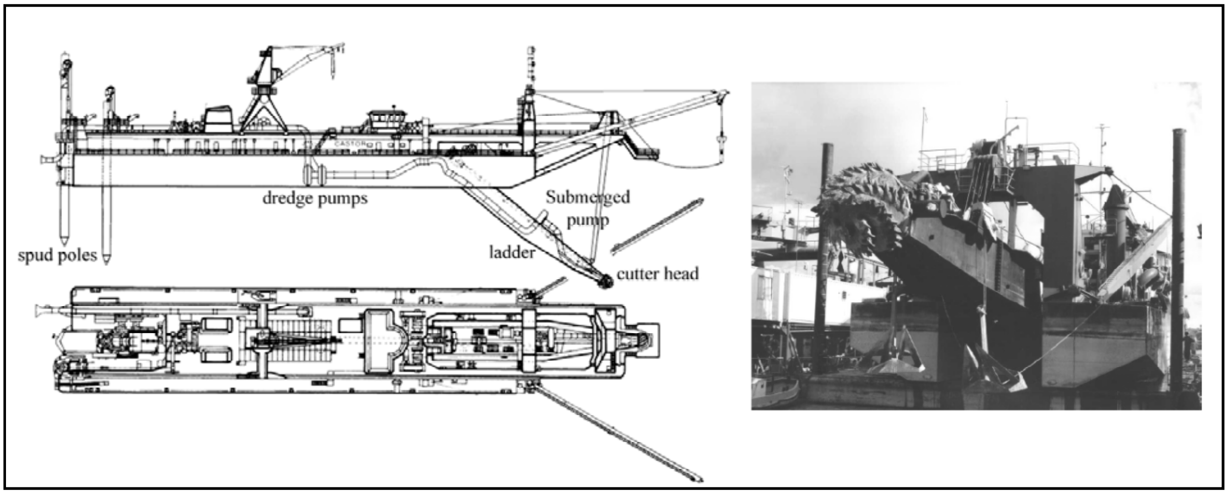

Figure 8. Rotary (basket) Cutter Suction Dredge HAM 219

The less common form of cutter head is the bucket wheel. The bucket wheel excavator is a series of rotating bottomless buckets mounted on a lateral shaft. Material, once liberated, enters the inner chamber where it becomes entrained in the suction stream and becomes a slurry. The bucket wheel was first developed in the United States during the 1970s and has been used increasingly in the mining of heavy minerals. **Figure 9** shows the bucket wheel profile and its key component, the bucket wheel.

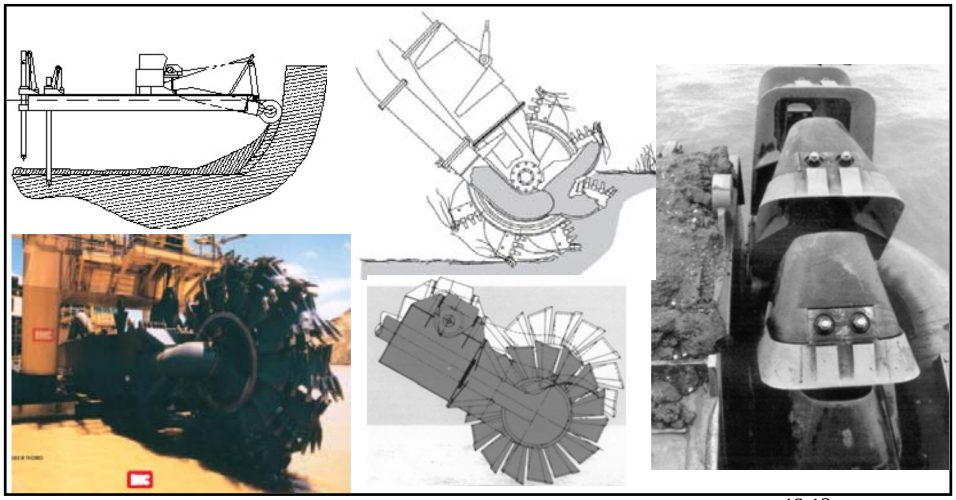

Figure 9. Bucket Wheel Dredges and Cutting Head[12,13]

While the bucket wheel dredge has some advantages over a basket cutter, the following key disadvantages often outweigh the benefits:

- Greater mass and machine complexity,
- More susceptible to blockages,
- Need for controlled uniformed feed at the digging face,
- Unable to effectively mine rock or hard lenses, and
- Material excavated may not enter the buckets and require rehandling (**Figure 9**, top left corner).

As discussed previously, the most common type of cutter configuration is the rotary, basket, or rosebud cutter head. Depending on its specific configuration, it is capable of excavating a wide variety of materials, ranging from sand to clay to solid rock. **Figure 10** shows a rotary cutter head with a dredge suction inlet visible while **Figure 11** illustrates some standard cutter designs

Figure 10. Rotary Cutter Showing Suction Inlet[12]

[12] Turner, T Fundamentals of Hydraulic Dredging Second Edition ASCE Press 1992
[13] A quarter of a century of successful IHC wheel dredgers. IHC reference document pd167_22-tm27.pdf 2006

as well as the recently commissioned rock cutter dredge being used as part of the Panama Canal expansion.

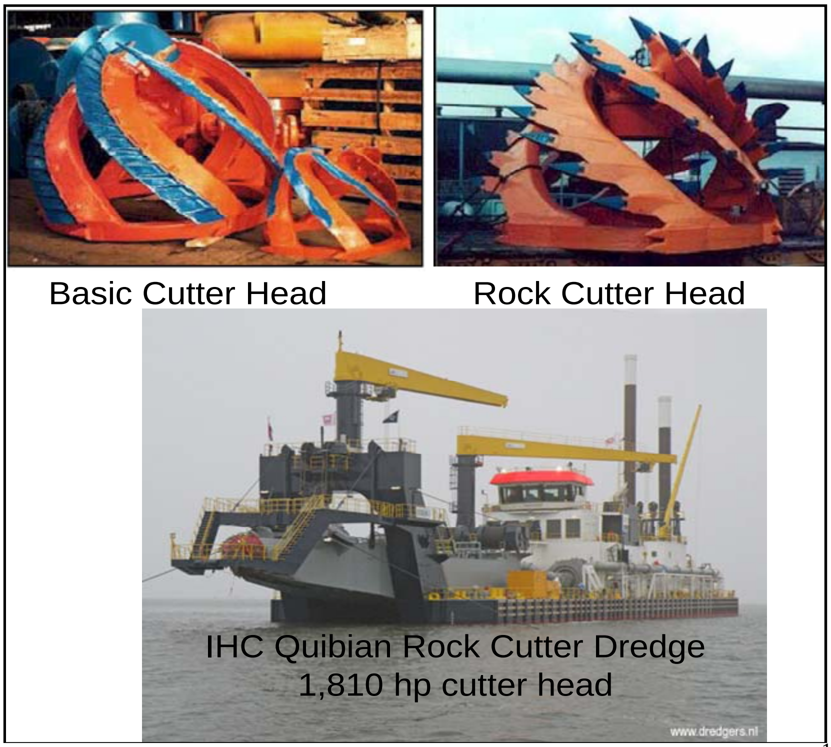

Figure 11. Rotary Cutter Heads and Panamanian Dredger Quibian[14,8]

Near size material that passes the cutter head's openings can be very problematic for the same reasons as with plain suction dredges. However, when these problems occur, the results can be substantially worse, as the cutter head continues to operate liberating material that is no longer being drawn into the suction pipe. This can result in substantial losses and sediment pollution around the dredge head. To limit these problems, operators have tended to use bigger and more powerful dredge systems. The larger dredge is designed to deliver more mechanical energy to the material being excavated. While such dredge systems can be designed to excavate almost any material, they have a number of drawbacks. In addition to higher capital and operating costs, their digging depth can be limited by the mass of the dredge ladder and the resulting dredge platform needed for support. The increase in mass not only limits the depth of material to be excavated but also increases the minimum depth needed to operate. Another means of increasing the energy transfer from the cutter head to the excavation surface is to spin/rotate the cutter head faster in relation to dredge movement so that each tooth or impact point needs only to liberate a smaller volume of material. As can be expected, this will likely increase material losses and increase sediment suspension. These loses can easily exceed 25% and may reach 50% for hard material initially excavated by the cutter head[15]. This results in the need to dig below the planned bottom contact and to try to recover the spilled material through multiple passes. In addition, the

[14] https://www.dredgepoint.org/dredging-database/equipment/quibian-1

[15] Burger M., Design Aspects for Cutter heads related to the mixture forming process when cutting coarse materials., Terra et Aqua Number 98 March 2005.

losses associated with heavy (high specific gravity) minerals can be substantially higher as more material is likely to be placed outside the influence of the suction assembly.

Despite these limitations, the rotating cutter head is one of the most widely used dredges to mine rock and many economic minerals. While improvements to the rotary cutter dredge systems would reduce their losses (increasing production and reducing sediment suspension) as well as lowering the cost of total product production, there has been limited research in this area, outside of cutter head designs, to improve their ability to cut rock and other competent materials[16].

To promote mixing and to supplement the energy delivered to the cutting face, some cutter suction dredgers have been equipped with waterjet assemblies, where one or more jets are mounted on the sides of the ladder close to the cutter ring (**Figure 12**).

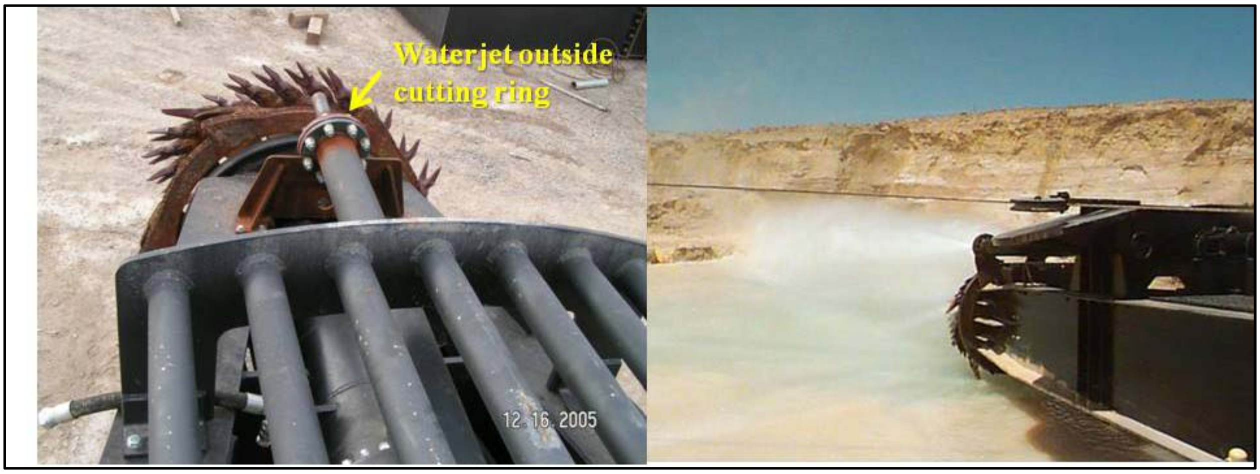

Figure 12 Dredge Supply Company's Waterjet System with a Cutter Head

The limited use of waterjets, in combination with cutter dredges, has been confined to softer sand materials and directed towards loosening the material outside of the cutter head. There has been a limited amount of research undertaken to improve the dredge performance once the material has been liberated. Most research has been focused on improving the rotary cutter head's ability to liberate/break rock or hard sediments[15].

[16]Burger M., Thesis Mixture Forming Processes in Dredge Cutter Heads 2003

2.4 Basic Problem with Dredging

In the dredging industry, the specific cutting energy is described as the amount of energy that must be added to excavate a unit volume of soil (*e.g.*, sand). The units most commonly associated with specific cutting energy are kilonewtons per cubic meter or kN/m^3. The specific cutting energy can be applied in one of two ways. The energy is transferred either hydraulically or mechanically to the material being excavated. The material, once liberated, is then carried toward the suction pipe via entrainment in the stream of water being drawn into the suction pipe. Once in the pipe, the material and water are then transported as slurry. While both hydraulic and mechanical dredging methods are capable of excavating a variety of materials, they each have limitations, particularly when encountering compacted or conglomerated material of differing sizes and hardness. Current advances have allowed rotary cutter suction dredges to be able to mine almost any material; however, their efficiency and costs in doing so is limited. These limitations fall into three broad categories.

1) **Bottom Losses**: Bottom losses occur when material fails to become entrained in the suction stream and falls out towards the bottom of the water column or into the environment. These losses tend to be more extensive for the heaviest and lightest materials. In mining applications, the heavier materials (minerals) are often the items of greatest economic importance. The lighter materials may not have economic value but their resulting sediment cloud may be unacceptable from an environmental and operational perspective.

2) **Material Blockages:** Material blockages occur when oversize or near oversize material blocks or partially obstructs either the suction pipe or the dredge pump. Operationally, this may result in shutting the dredge down to clear the blockage or in the case of near size material, continuing to run at a reduced efficiency until the blockage clears. In both cases, blockage can result in substantial increases in pond bottom losses during the blockage period.

3) **System Inefficiencies**: The key equipment components (pumps, motors, cutter heads) are often oversized to handle the irregularities encountered, resulting in increased inefficiencies and potentially compounding the problems associated with (1) and (2), above. In addition, the material, once dredged, will have a larger size distribution that may negatively impact downstream processing.

3.0 THE USE OF WATERJETS TO INCREASE PERFORMANCE OF ROTARY DREDGES

To overcome these problems, it is proposed that a system be designed that utilizes a unique combination of cavitating waterjets with a standard rotary cutter dredge. The waterjet nozzles will not be aimed external to the cutter head as is current practice, but rather arranged toward the intake suction creating a cavitating vortex. It is believed that by deploying the jets in this manner, the following improvements will occur:

- Improved suction capacity of the dredge system reducing bottom losses,

- Assist in improving comminution/sizing of the material, reducing the potential occurance of blockages, and limiting the need to oversize or employ additional equipment, and
- A reduction in the overall energy consumption.

The cutter head is responsible for the excavation of material, as well as creating a water/soil mixture suitable for hydraulic transportation by the suction pipe. In this configuration, the cutter head and drive unit are mounted on the dredge ladder (**Figure 10**). The cutter head drive shaft and hub are connected by means of a screw joint. A cross section of the cutter head when it is positioned in the breach/bank is shown in **Figure 13**.

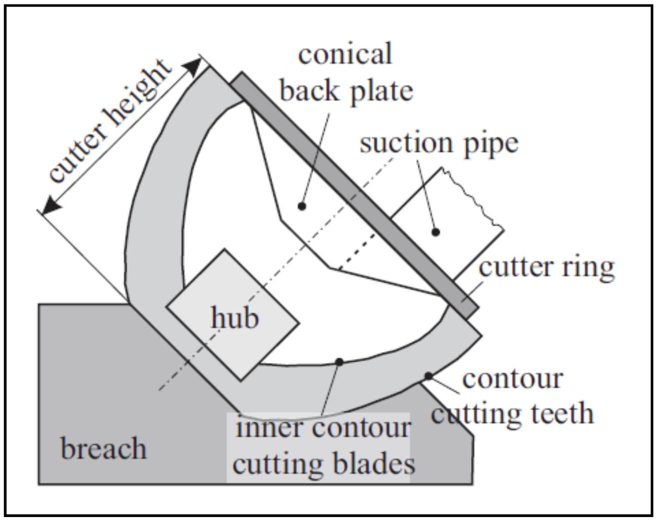

Figure 13. Cross Section of Cutter Head in Breach Bank[15]

It is important to note that approximately half of the cutter head is placed in the breach (not the entire cutter head), which is typical for the cutting of hard formations and where the cutting forces are relatively high[16]. Once the material has been excavated, it is moved toward the suction pipe by two primary forces:

1) The velocity of water being drawn into the suction pipe, and
2) The centrifugal forces and water flows being generated by the turning of the cutter head.

It should be noted that for heavy or larger particles, the force of the intake suction may not be sufficient to entrain the particles until they are very close to the suction intake. This fact makes the need for sufficient force to be created by the turning of the cutter head at a certain angular velocity. Unfortunately, at a certain rotational speed, the centrifugal forces and pump effect is greater than the suction intake and material is expelled near the cutter ring. The balance between rotating too fast or too slow can be complicated by the need to have sufficient velocity in order to excavate harder and/or larger material. The effects of rotational speed can be seen in **Figure 14** and **Figure 15**, which show pictorially and graphically the effect of differing rotational speeds.

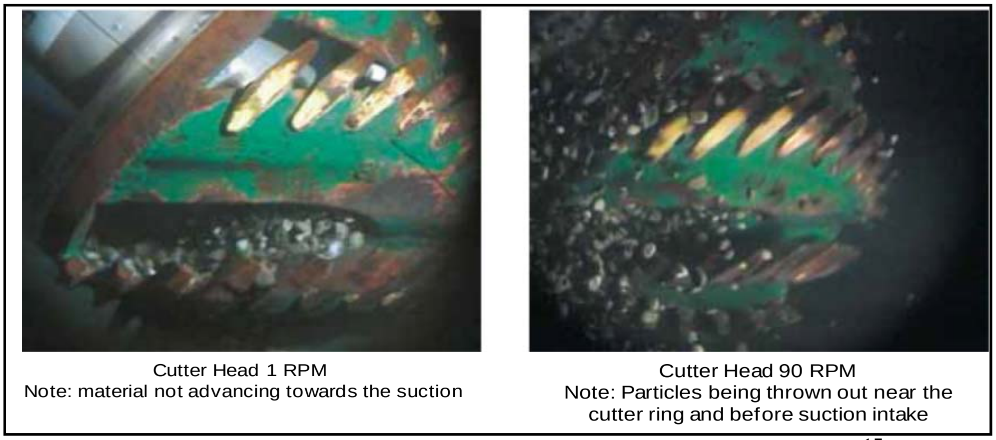

Figure 14. Material Flow in Cutter Heads Different RPMs[15]

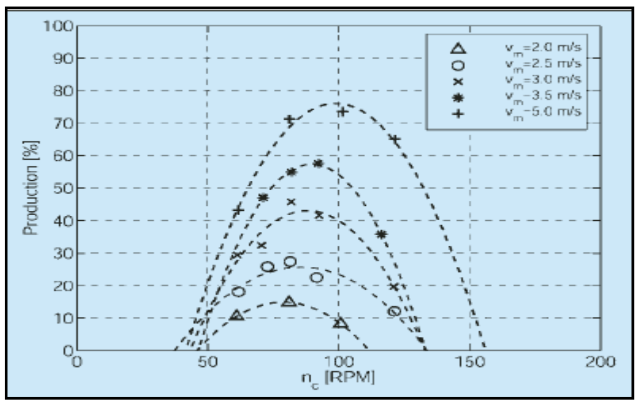

Figure 15. Production versus RPM of Cutter Head for Different Mixing Suction Velocities[15]

To overcome the current deficiencies associated with rotary cutter heads, it is proposed that the addition of high-pressure waterjets arranged within a rotary cutter head (**Figure 16**), will improve its performance for a variety of materials.

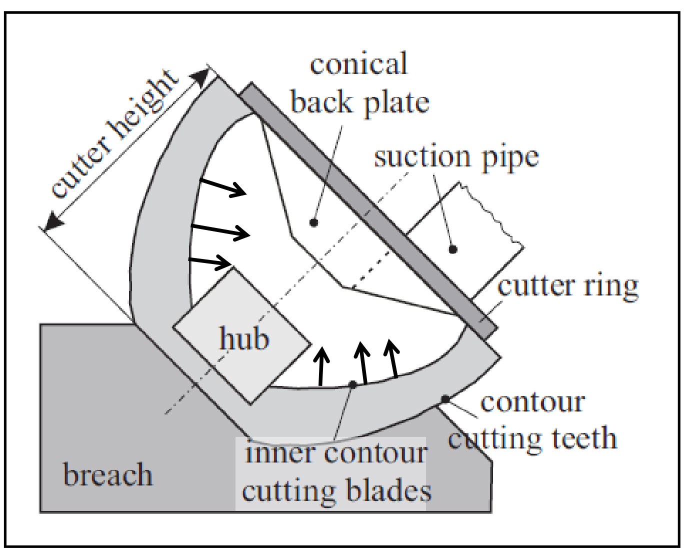

Figure 16. Graphic Depiction of Waterjets (arrows) Within a Rotary Cutter Head

It is believed that the introduction of strategically oriented jets will perform three functions:

1) By creating a vortex flow, they will assist in moving material towards the suction intake,

2) Confine the material within the cutter head, thereby minimizing losses, and

3) Provide additional comminution by creating a cavitating zone and by increasing material interaction within the vortex.

If these three functions can be achieved through the addition of high-pressure waterjets, it will result in several benefits:

- Reducing the amount of spillage while dredging and thereby, increasing production and recovery rates as well as reducing sediment suspension and pollution.

- Creating an environment where comminution of the larger particles takes place away from the suction intake. This process will lessen the potential for partial blockages and the need for additional comminution at the surface. It will also allow for increased pump efficiencies as the pump can be sized to handle smaller material and reduce the amount of spillage of larger and heavier particles.

- Allowing the rotation speed/torque of the cutter head to be adjusted to increase excavation productivity.

- The resulting system will provide a means of dredging deposits and materials that were previously not technically or economically viable.

4.0 CONCLUSION

It is theorized that by utilizing waterjets on a traditional rotary cutter head, there will be an increase in productivity, a reduction in suspended sediments, spillage and particle sizes, and improved efficiencies when encountering hardpan or other solid material. The validation of these anticipated benefits is currently underway as part of Ph.D. dissertation research project at the Colorado School of Mines.

As part of this research effort, an experiment utilizing cavitating waterjets is being proposed in association with Texas A&M's Haynes Laboratory utilizing a standard rotary cutter head with and without waterjet assistance. **Figure 17** shows the proposed waterjet testing apparatus

Figure 17. Location and Sketch of Waterjet Testing Apparatus

The dredge test facility is capable of collecting information on dredging operations that allow the cited theories to be tested (**Figure 18**).

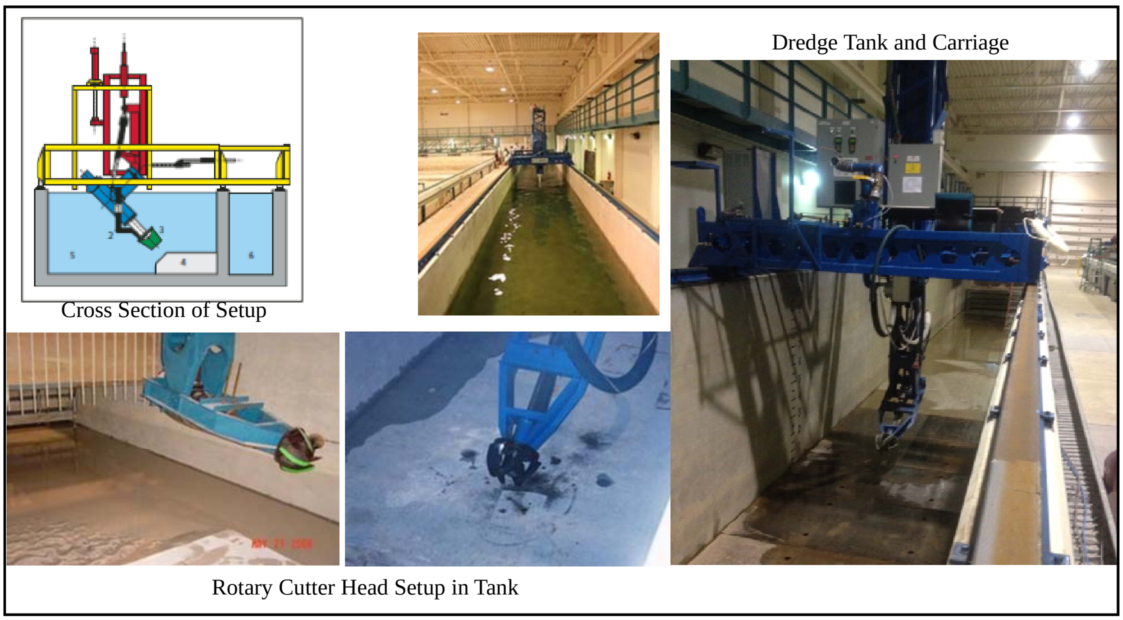

Figure 18. Texas A&M Dredge Facilities

If cavitating waterjets are used the following should be achieved:

1) Suspend the material such that it can be entrained in the suction intake stream with measurable differences in bottom losses and reduction in suspended sediments,

2) Reduce the size of the material entering the dredge suction, resulting in a measurable size reduction in the product discharge,

3) Measure a reduction of the pump component of the velocity stream (while maintaining a constant cutter head rotational velocity) needed to transport the material into the suction intake, and

4) Measure a reduction of the cutter head rotational velocity (while maintaining a constant pumping velocity) needed to transport the material into the suction intake.

If the above can be achieved on an experimental basis, it is likely the development of a new more efficient class of dredge systems utilizing high pressure cavitating waterjets will follow. This research is scheduled for completion in January 2014.