Proposal for the Redesign of the Halliburton FB4K Blender Auger System

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Contents

Executive Summary

Halliburton contacted Biosystem and Agriculture Design Company (BAD Co.) to develop a solution to an issue that they have experienced with the FB4K Blender. The FB4K Blender uses three sand screws, three dry feeders, and seven liquid additive systems to blend together a variety of proppants and liquids. The specifications of the mixture can be altered to accommodate the job at hand. The three sand screws, which move the proppant into the blender, are the source of the issue that we are faced with. The output experienced by the screws remains linearly proportional to the speed of the screw until it nears its peak RPM. Each screw experiences a decline in output when the operating speed reaches a certain point. We are faced with the task of accounting for this decline in output. To solve the problem, we will first develop an equation that describes the loss of production. This equation is able to be integrated with the FB4K's operating system to adjust the output of the liquid additive system as the output of the screw conveyors declines. Second, we will propose a new design for the sand screw that will allow a higher range of linear output. It is our goal to provide Halliburton with a solution that can be simply integrated with their current process.

Statement of Problem

Halliburton has given us permission to review their current designs and test data. We have been asked to improve the accuracy of the data and increase the effective operating range of the design. This will be done by finding an equation that characterizes the auger output past its linear range of operation. Once the accuracy and operating range are satisfactory, we are asked to propose a new design for the screw conveyor system. This new design will be tested to see if the changes make any improvement. Our goal is to design a conveyor system that shows less decline in output than the current design in production.

Identifying Customer Needs

"We would like for you to review at our design and test data and propose some changes you would make to improve accuracy and operating range. From there, we would like you to build prototypes of different size augers (does not have to something we could put into production) and test to see if the changes make any improvement. I think the prototypes should be 6" or smaller, otherwise the output will be very difficult to handle. We can provide some monetary assistance with this (would like to keep it between $5-10k). We would also like you to look into an equation to characterize the auger output past its linear range of operation."

–Chad Fisher, Halliburton

Design Objectives

- Use current design data to derive an equation that describes auger output at all ranges.
- Propose design changes that will improve accuracy of auger output at high RPMs.
- Build a prototype of the designs which offer the most probable solution to the problem.
- Test our prototype using different grades of commonly used proppants.
- Review and analyze prototype test data to determine the accuracy of new design.
- Derive an equation that describes the newly designed auger output at all ranges.
- Compare current design and prototype data.

Statement of Work

The purpose of our project is to determine why Halliburton's augers on the FB4K Blender have a declining output when operating at high RPMs. We will discover the source of the problem by first analyzing test data that has already been gathered by Halliburton. We will produce an equation that describes the output of the auger at varying RPMs. We will also design and test a prototype that may or may not be capable of being put in to production.
Using the provided output versus RPM data that has been provided, we will create a model that simulates the auger's production. This model will allow us to diagnose what part of the system we will alter to improve the output. We will redesign one or more parts of the auger and build a prototype. Running tests on this prototype will provide data that shows if our new design improves the output. We will then make an equation that describes the output of our new design.

In order to deliver equations and a prototype, we will need to:

- Analyze the test data provided to us.
- Enter the data into modeling software and carry out simulations.
- Analyze the simulation results to develop an equation describing the output.
- Generate design concepts to consider for implementation.
- Select the most effective design concept to propose.
- Design the proposed change using SOLID WORKS.
- Submit proposals to Halliburton for them to decide which one we should manufacture and test.
- Test prototype and use data to create a new equation that describes the output of the new design.

Period of Performance

By November 16th, we had produced equations that represent the output of multiple sizes of augers at variable speeds. All of our design options were finalized by November 26th. On December 5th, we presented all of our design options and other solutions to Oklahoma State University staff and students, as well as Halliburton employees. We had our test setup and prototype ready to run control tests on April 5th. Testing for the final prototype was completed on April 19th. All data was processed by April 22nd, and we presented our findings on April 25th. We visited Halliburon's facilities in Duncan, Oklahoma twice during the fall semester, but were unable to visit during the spring semester.

Deliverables Schedule

Fall 2012

- Equation for the nonlinear curve from given data for the 12 inch auger
- Multiple designs to correct nonlinearity
- Proposal to present findings and possible solutions

Spring 2013

- Prototype of each viable design change
    - Control
    - Enlarged bin
    - Removed tube extension from bin
- Test data from each prototype
    - Convert data to lbs/min
    - Plot data in Excel
- Equations that describe performance of prototypes
    - Use TableCurve to find equations that describe prototype outputs
    - Compare control auger performance with each prototype
- Final report comparing new test data and equation to originals
    - Interpret data to find specific reason for non-linear output

Applicable Safety Standards

Augers do a lot of hard material handling work that would otherwise be done manually. Augers also can cause many injuries due to a lack of awareness of the possible dangers. Shield should be properly installed on our test auger to prevent materials from being thrown from the setup. Shields will also prevent users from becoming tangled in the equipment. Wearing close-fitting clothes when operating the auger will also help us to avoid becoming tangled in the auger. If our test auger has wheels on it, it will be very important to put blocks behing the wheels for stability. If the auger does not have wheels, the base must be stable enough to not tip over. Every test, the auger should be completely emptied to avoid issues when restarting the auger for the next test. As with all experiments, protective eyewear should be worn at all times when the equipment is running. Standard testing safety procedures (eye, ear, clothing protection) apply. Stay clear of all operating equipment during testing. Our prototype will only be used for testing, and will not be put into production. Therefore will not need to consider industry safety standards, and only put safety precaustions in for ourselves.

Technical Specifications

We are presented with two different sizes of augers:

- The 6 inch auger produces up to 800 lb/min at 400 RPM.
- The 12 inch auger produces up to 9000 lb/min at 400 RPM.

Strengths of each auger:

- The drive for the auger is adequate for the current usage.
- 6 inch auger has linear output up to 200 RPM, where it sees an output of 500 lb/min.
- 12 inch auger has linear output up to 200 RPM, where it sees an output of 6000 lb/min.

Weaknesses of each auger:

- Above 400 RPM, the output rate starts to decline.
- The material feed rate may be too slow to entirely fill the auger.
- The pitch and flighting may not be optimized to be completely filled on every rotation of the screw.
- The angle of the hopper may not allow the proppant to properly fill the auger.
- The space between the auger and its housing tube may allow sand to fall between flights.
- Housing extending into hopper limits proppants availability to auger.

Possible Solutions:

- Use output detecting sensor to adjust mixing fluid input.
- Change flighting of the current augers (length, thickness, spacing, and angle of blade).
- Change angle of the whole auger.
- Integrate an equation into a control system that will calibrate automatically for the output decline.
- Change hopper design.
- Make tighter tolerance between screw and housing.

Acceptance Criteria

Acceptable work for out project will include multiple solutions for the problem presented. We will have one solution that does not involve any altering of the auger itself, but rather an equation to be programmed into the operating system that will account for the decline in output. Another solution will be a proposed change to either the auger or hopper bin design that allows a linear output at increased RPMs. We will evaluate our proposed design options by assessing how well it increases the linear range, how easily it is integrated into the existing system, and the costs associated with this integration.

Modeling

There are several areas of the auger which we would have liked to produce models for. We will acquire a screw and tube that is similar to the six inch auger currently in production. Also considered for modeling is the hopper attached to the bottom of the auger. Various hopper designs may ensure that there are absolutely no voids in the proppant around the screw during high speeds. The dimension of the auger's flight and pitch within the hopper is another area that we will research and model. We will also produce an equation to improve our accuracy in measuring the expected output of the auger.

Simulation

We will enter the data, given to us from Halliburton, into a software program that will generate an equation for the data points. This equation will tell us more about the problem and help us figure out a solution. After we conduct our own experiments we will enter that data into the same software. We will then compare the two equations to show how our design(s) changed the output.

Experiments

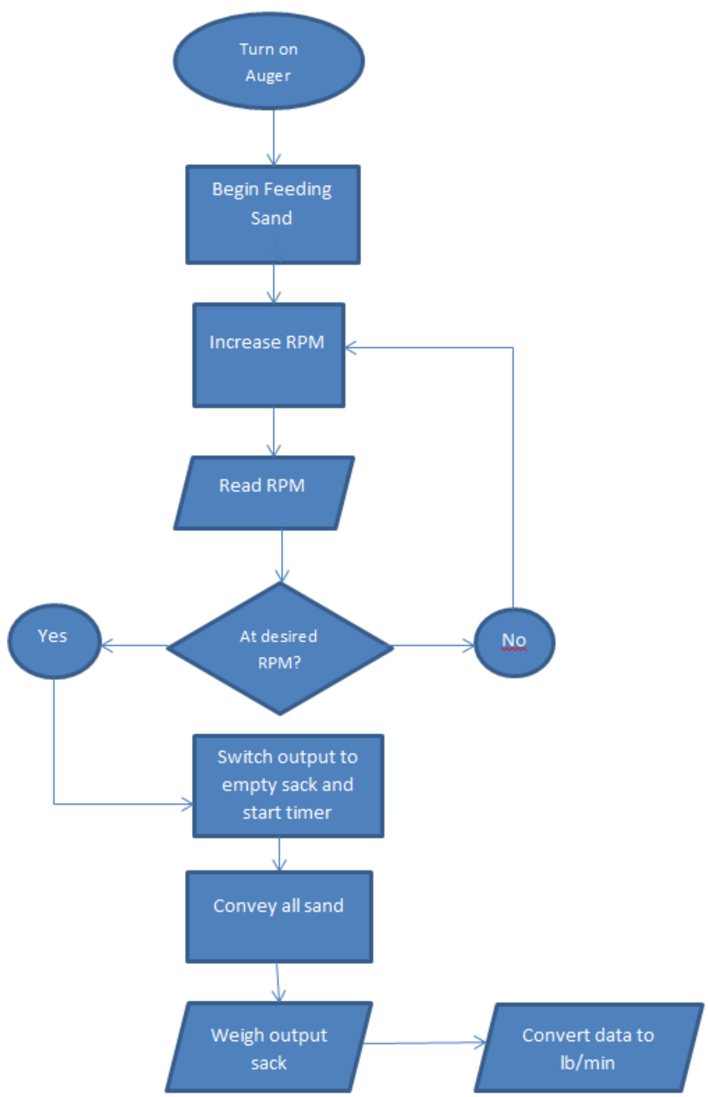
We will construct multiple prototypes for testing. Our control test will be conducted using an auger obtained from Halliburton's stock. We will be testing their six inch design only. We are not able to test the twelve inch design because of the amount of material required for that design. We will fabricate a stand to simulate the use of the auger when it is on the FB4K. This test will use a fill bin the same size as Halliburton's current design. After data has been collected for the control test, the same test will be conducted using the design variations discussed in this report.

Procedure:

The screw is set at a 45 degree angle on the test stand. Two empty sacks are placed side by side on a stand below the auger's output chute. The chute has a diverter which can direct the sand into either sack. Using a forklift, a full sack is lifted above the hopper. The motor's hydraulics are hooked up to a John Deere 6240 tractor.

Once power is directed to the screw, the bottom chute of the full sack is opened, delivering sand into the hopper. This sand will begin to fill one of the empty bags. Using the incremental encoder, we will be able to tell what RPM the screw is operating at. Once the screw has reached the desired RPM, we will move the diverter at the output to begin filling the other sack. A timer will be started as the diverter is switched. After all the sand has been delivered through the auger, the timer will be stopped. The weight of the sand in the sack will be measured. From this, we will convert the output data to lb/min.

Tests will be run in 100 RPM increments.



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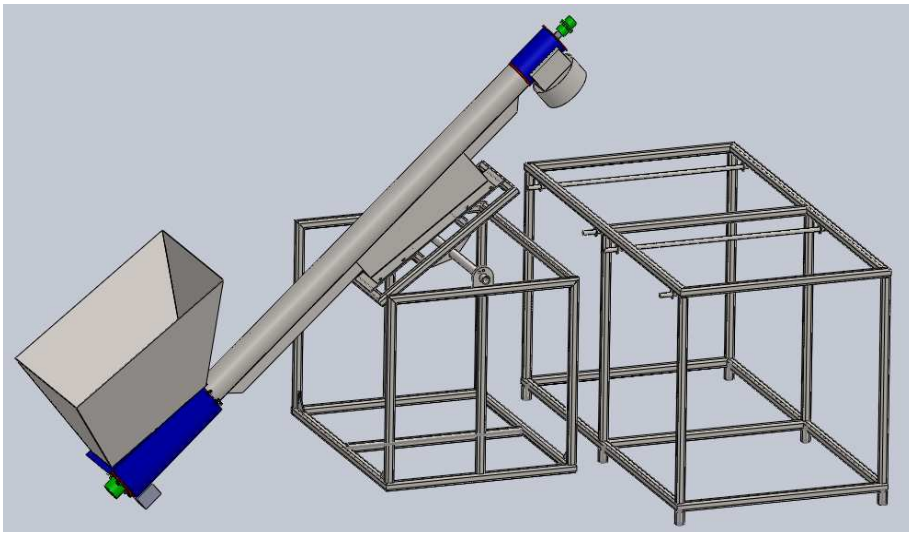


Data Collection Required for Concept Generation

Test data from both the twelve and six inch augers currently being used in production has been provided to us by Halliburton. Halliburton did not have data for the six inch auger ouside of its linear operating range. They did provide us with data outside of the linear range for the twelve inch auger. From this data, we are able to produce an equation that describes the output of the current design even outside of its linear range. This equation will give us a better idea of where design improvements need to be made. When testing our design prototypes, we will collect similar data that we can compare to the data from Halliburton's test. We will test the auger to see how many pounds per minute it delivers at various RPMs.

Development of Engineering Specifications

Using the data collected, we will alter the specifications of the current design to optimize the linearity of the auger's output. These will be the equations required to fully design our new sand screw. We will be taking into account the torque required, weight of total assembly, weight and volume of the proppant, force put on stand, force on the auger shaft, power required to drive the auger.

The *theoretical volumetric capacity* of an auger is expressed as:

$$Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n$$

Table 14.1
Q_t = theoretical volumetric capacity, m^3/s
d_{sf} = screw flighting diameter, m
d_{ss} = screw shaft diameter, m
l_p = pitch length, m
n = screw rotational speed, rev/s

For the six inch auger:

$Q_t = (\pi/4)\ (5^2 - 2.375^2) in^2\ (4in)\ (300RPM) = 18237\ in^3/min = 10.55 ft^3/min$

For 100 lb/ft^3 proppant, theoretical mass output rate = 1055 lb/min

In reality the actual capacity of an auger is *considerably less* than the theoretical capacity. This results in loss of volumetric efficiency. The *volumetric efficiency* is defined as:

$$\eta_v = \frac{Q_a}{Q_t}$$

Table 14.2
where η_v = volumetric efficiency
Q_a = actual volumetric capacity, m^3/s

For the six inch auger:

η_v = 615 / 1055 = 58%

Generally, the throughput rate is in terms of mass (or weight) per unit of time, for example t/h or kg/min, is specified. The volumetric capacity is obtained by dividing the throughput rate by the bulk density of the material.

The power requirement of an auger is expressed by the *specific power,* defined as:

$$P' = \frac{P/L}{Q_a \rho_b}$$

Table 14.3

where P' = specific power, W s/kg m

P = power requirement, W

L = auger length, m

ρ_b = material bulk density, kg/m^3

Thus, the specific power is the power required to convey a unit mass throughput rate per unit auger length.

For the six inch auger (with 5 hp motor):

P' = (5 hp x 5 ft) / [0.2183 (ft^3/s) x 100 (lb/ft^3) x (1 slug / 32.2 slug)] = 1.48 (hp·s/slug·ft)

Table 14.1 shows a list of variables that are pertinent to the problem. These variables can be combined into ratios or dimensionless groups called the pi-terms using Buckingham's Theorem (see Chapter 1). The following equation includes the dimensionless terms:

$$\pi_1 = f\left(\frac{d_t}{d_p}, \frac{d_{sf}}{l_p}, \frac{d_{ss}}{l_p}, \frac{l_i}{l_p}, n\sqrt{\frac{l_p}{g}}, f(\theta), \mu_1\mu_2\right) \qquad (14.4)$$

where

$$\pi_1 = \frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\, l_p n} \quad \text{or} \quad \frac{P/L}{Q_a \rho_b g} \qquad (14.5)$$

The first term in the right hand side of Equation 14.5 is the ratio of the actual volumetric throughput rate to the theoretical volume swept by the screw per unit of time. This has been regarded as the volumetric efficiency of the screw conveyor. The second term in the right hand side of the above equation is the power required per unit length per unit mass flow rate of the material being conveyed. It has been defined as the specific power or the power efficiency of the conveyor. The conveyor length does not affect the volumetric efficiency.

The dimensionless terms of Equation 14.4 were used to develop prediction equations using experimental data. Published data on the performance of auger conveyors conveying wheat, oats, and shelled corn were used to develop the performance equations. These equations may be used to estimate conveyor performance for similar materials.

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\ l_p n} = (4.332\times10^{-4})\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{-0.44}\left(\frac{l_i}{l_p}\right)^{0.31}\left(f_1(\theta)\right)^{1.35}\mu_1^{-4.59}\mu_2^{-3.72} \tag{14.6}$$

$$\frac{P/L}{Q_a\rho_b g} = 3.54\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{0.14}\left(\frac{d_{sf}}{l_p}\right)^{-10.12}\left(\frac{l_i}{l_p}\right)^{0.11}\left(f_2(\theta)\right)\mu_2^{2.05} \tag{14.7}$$

where $f_1(\theta) = 1 + \cos^2\theta$ (14.8)

$f_2(\theta) = 6.94\ (1.3 - \cos^2\theta)$

θ = conveyor angle as measured from the horizontal, degrees

$0.414 > \mu_1 > 0.374$

$0.554 > \mu_2 > 0.466$

Equations 14.6 and 14.7 do not apply to materials similar to the proppant used.

Table 14.1. A list of variables affecting screw conveyor performance.

Symbol	Variable definition	Dimensions	Units
Q_a	actual volumetric capacity	L^3/T	m^3/s
P	power requirement	ML^2/T^3	W
d_t	tube inside diameter	L	m
d_{sf}	outside screw diameter	L	m
d_{ss}	screw shaft diameter	L	m
L	screw length	L	m
l_p	screw pitch length	L	m
l_i	exposed screw intake length	L	m
n	angular speed	1/T	rev/s
θ	angle of conveyor inclination	-	degrees
ρ_b	material bulk density	M/L^3	kg/m^3
μ_1	material-metal friction	-	-
μ_2	material-material friction	-	-
g	acceleration of gravity	L/T^2	m/s^2

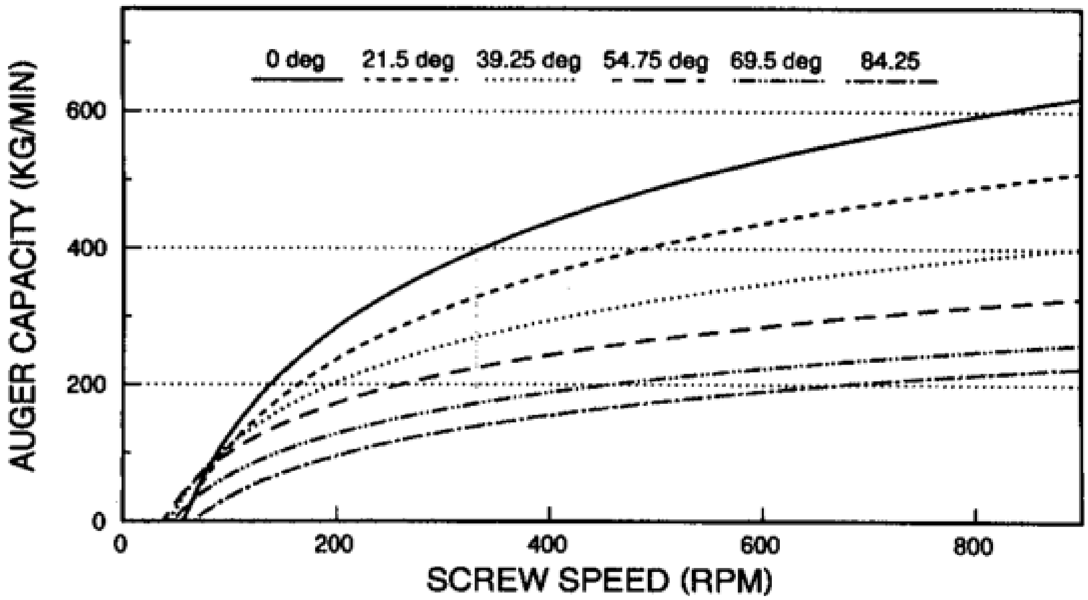


Figure 14.2 - Effect of screw speed and angle of auger inclination on conveying capacity (redrawn from Regan and Henderson, 1959).

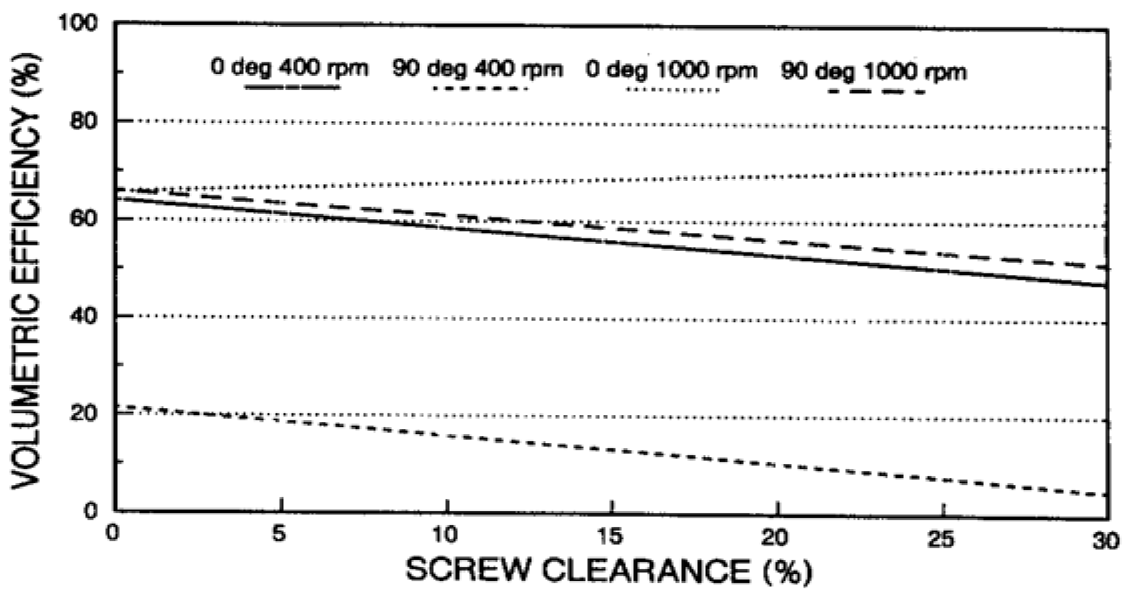


Figure 14.5 - Effect of the clearance between screw flightings and the tube inside diameter on the volumetric conveying efficiency (redrawn from Brusewitz and Persson, 1969).

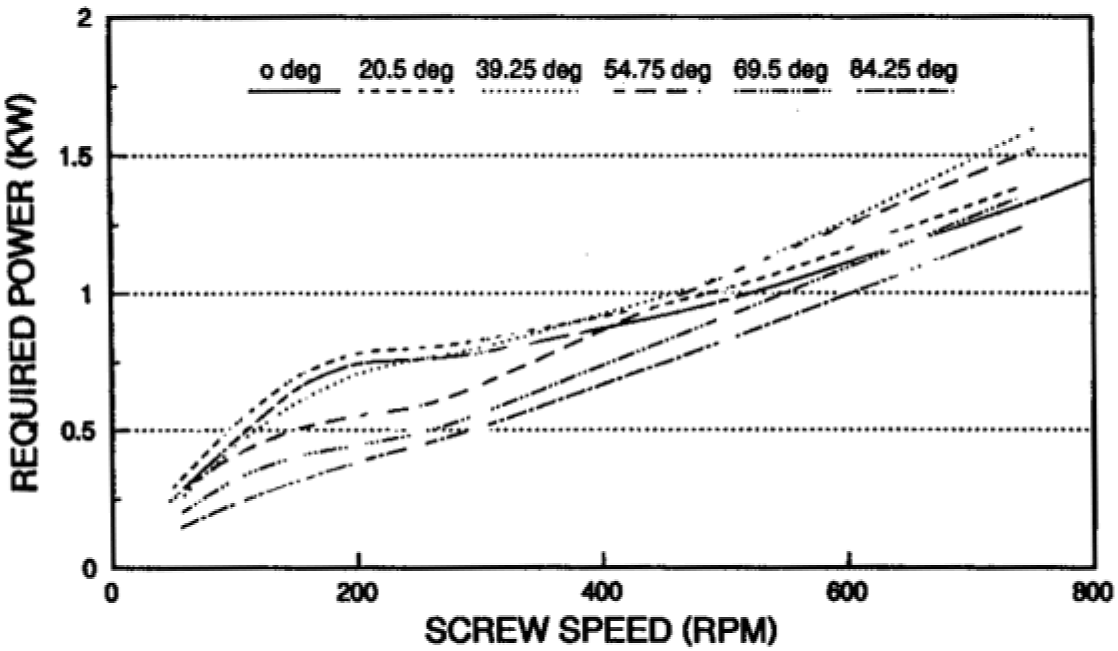


Figure 14.6 - Auger conveyor power requirements at different screw speeds and angles of inclination (redrawn from Regan and Henderson, 1959).

Equipment Needed

To build our prototype, we acquired a used auger from Halliburton. The rest of our setup was fabricated in the BAE Lab at OSU. We fabricated a hopper for the top of the bin to direct the sand from the sack into the bin. We attached an output chute to the discharge section at the top of the conveyor to direct the sand into separate sacks as it comes out. We made a stand to hold two supersacks adjacent to eachother which will be used to hold the output. We to assembled another stand that holds the test auger at approximately 45 degrees, the same angle that is used on the FB4K blender.

Identifying Target Specifications

Halliburon has specified that they would like us to meet a degree of accuracy of 5%. We will choose an equation with an R^2 value above 95%. Anything less will not be worth integrating into the existing system.

Generating Design Concepts

Halliburton suggested that we not dismiss any part of the system when diagnosing the problem. We looked at a few different parts as possible causes for the problem at hand. One possible issue involves the feeding rate of proppant to the bottom of the auger. The bin's current design might not allow proppant to completely fill the space around the auger every rotation. Another possible issue lies within the tube itself. Augers operate under similar concepts as a positive displacement pump. This means if the material is in the system, it will be moved as long as the system is operating properly. The decline in production at high speeds might be due to the centrifugal force in the system causing the sand to move to the outer edge of the tube, where the auger does not reach. The final part we looked at was the auger's flighting. The pitch, angle of flighting, and shape of flighting all play a role in the productivity of the auger. Altering the flights in some fashion may cause an increase in overall productivity, as well as linearity of output. After considering all these parts as possible areas of concern, we were able to derive several options for redesigning the auger.

Option 1

Increase intake bin of the bottom of the auger

- Because its not feeding as fast as the auger can take the proppant up.
- Not filling up fast enough.
- This will allow for more proppant to fall around the auger at the entrance so there will not be voids in area where there is no proppant.
- This will be able to be done by increasing the area surrounding the bottom of the auger.

Option 2

Change the pitch and flighting of the auger

- Making the pitch longer will give the proppant more time to fall between flights in the hopper. This increase in time will allow more the proppant to entirely fill up the space between flights.
- The proppant will have more time to fill the larger area, even at high RPM.

Option 3

Add a horizontal sand screw

- It will fill the area around the bottom of the auger more efficiently.
- The horizontal screw will prevent gravity from causing the proppant to fall away from the entrance to the auger. better when it is going horizontal at first.

Option 4

Decrease the diameter of the tubing surrounding the auger

- This will give us a tighter distance tolerance between the auger and the surrounding pipe.
- This will decrease the amount of wasted sand that does not make it all the way up when the auger is running.
- This will also increase our ability to measure the accuracy of the auger
- This can also be done in reverse by increasing the size of the auger itself instead.

Option 5

Give the flighting a concave cross-section

- Concave flighting will compensate for any proppant that is lost between the auger and the tube due to centrifugal force.
- This may in return give us more of an accurate reading of how much proppant is actually being used.
- Higher carbon content makes outer edge more durable.
- See Appendix G for more information about UltraFlyte flighting.

Option 6

Removal of tube from hopper

- Remove section of auger tube that extends into hopper.
- Expose the auger to a larger volume of proppant in the hopper.
- Increase the overall volume of the hopper.
- Put a flange at the end of hopper to support tube.

Option 7

Decrease outer diameter of auger shaft

- The current design has a shaft with an outer diameter of 2 3/8”
- We believe this shaft is excessively large for use in the 6” auger.
- A smaller outer diameter will open up more space for proppant in the hopper and inside the housing.
- If the design of the 12” auger is scaled down to a 6” design, the shaft will have an outer diameter of 1 ½ inches.

Selecting Design Concept

We believe that the best possible design change is the one that increses the linearity of the auger's output while also increasing the overall rate of output and quality of auger. Each design option offers a different valid solution to the problem. At the same time, each design option presents the challenge of being integrated into the system. The design chosen should be capable of being implemented on the current product with little difficulty. Costs associated with implementing the design are also taken into consideration when choosing the best concept.

Option one assumes that the issue at hand is strictly a fill issue. At high RPMs, the auger is rotating too fast for the proppant to fall due to gravity and completely surround the auger. A larger intake bin will introduce a higher volume of proppant surrounding the bottom of the auger. This increase in volume will not increase the output of the auger at low RPMs, where the proppant has time to fully engulf the auger on each rotation. Increasing the size of the bin would require a new bin to be attached to each FB4K. Attaching the bins will entail installing a new mounting set up, and also a new intake for each auger. These integration challenges will be very costly, and will not have any effect on output until the auger nears its peak output.

Option two is a a design that only affects the pitch of flighting in the auger. A larger pitch will require less flighting per length of auger. This decrease in flighting will make more space available in the tube for the proppant to fill up. It will also give the proppant in the hopper more time per each revolution to fill the space between flights. If the same amount of proppant is being provided to the auger, the auger should be able to fill more efficiently at high speeds. Because of the increased volume of proppant being delivered per rotation, the overall output of the auger will increase. Integrating the redesigned screw into the new system would require little change to the current system. The tubing, feeding mechanism, and drive would remain the same. Removing the existing sand screw, manufacturing the new one, and installing the new one are the costs associated with this design option.

Option three involves the redesign of two pieces of the current system. First, the bin would be redesigned to be allow the proppant to enter the screw when it is parallel to the ground. Second, the screw will have to have a bending joint at the bottom of it to attach to another length of screw that will be horizontal. The current design allows gravity to pull the proppant downward, away from the point it enters the tubing. Implementing a horizontal bin would evenly distribute the proppant over a length of screw before entering the tube. Instead of the screw pulling the proppant diagonally upward towards the entrance of the tube, the proppant will be carried horizontally to the entrance of the tube. Once inside the tube, it will begin to be pulled upward. This design option will require a very complex implementation process. Attaching a horizontal fill bin to the FB4K will involve entirely redesigning the bottom of the current auger. Adding a length of screw and a new fill bin on top of it will make the FB4K longer. This will be a very costly process because of the amount of new materials required (new bin, screw, attachment to existing auger, and a means of mounting the new parts).

Option four focuses on the efficiency of the auger itself. In a perfect world, the auger would be in contact with the tube so that all proppant is being moved. In the current design, there is a half inch gap between the edges of the five inch auger and the inside of the six inch tube. This gap allows proppant to escape the flights and not be carried upward. This design option would decrease the inner diameter of the tube in order to narrow the gap between the auger and tube. This would cause a higher percentage of proppant in the tube to be carried by the auger with each rotation. The smaller tube may cause a decrease in the total amount of proppant carried, but the output will be more accurate at high speeds due to tighter tolerances. Reducing the size of the tube will call for replacing each tube on the FB4K. This process would require removing the existing tubes, attaching the new ones, and then refitting the hopper, drive, and possible bearings. To avoid replacing the tubes, the auger could be made bigger to fit the six inch tube more tightly. Doing this would avoid having to replace the tubes, and refitting the hopper.

Chemical components are often added to the proppant to avoid static build up in the blender once it is carried through the auger. Some of these chemicals will stick to the inside of the auger's housing. Occasionally, the chemicals build up due to normal use if not thoroughly cleaned on a regular basis. The demanding schedules of work in the fracking industry often don't allow for the augers to be cleaned adequately. The tolerance between the flights and the housing is to allow for a certain amount of build up to occur without causing the auger to lock up. Due to this unavoidable process, we have decided to omit option four as a viable solution.

Option five concentrates on the flighting of the auger. The current design has flights coming off the shaft straight at a right angle. Ultra Flyte's design has a concave face on the flighting of the auger. This helps increase the durability of the outer diameter of the auger by resisting the wear that traditional augers experience. The concave face also makes for faster conveying. On an 8" auger, Ultra Flyte has increased the output of standard augers by 90 bushels per hour (about 1.9 cubic feet per hour). The increase in output will be greater for the 12" auger, and smaller for the 6" auger. The concave design will improve the overall output of the design, as well as the linearity of output at high RPMs. Adding the concave design to the existing system will require the flighting of each auger to be replaced. The drive and the hopper attachment will not be effected.

Option six addresses a part of the system that we believe to be unnecessary. The housing of each auger on the FB4K extends about ten inches into the hopper. By removing this piece, proppant will be exposed to an extra ten inches of the sand screws. It will also increase the overall volume of the hopper just from being removed. A flange will be needed at the end of the hopper to support the housing. This design will not be difficult to implement with the current design, since it only involves removing one part. The cost will only be that of removing the part, and re-surfacing the area that is cut.

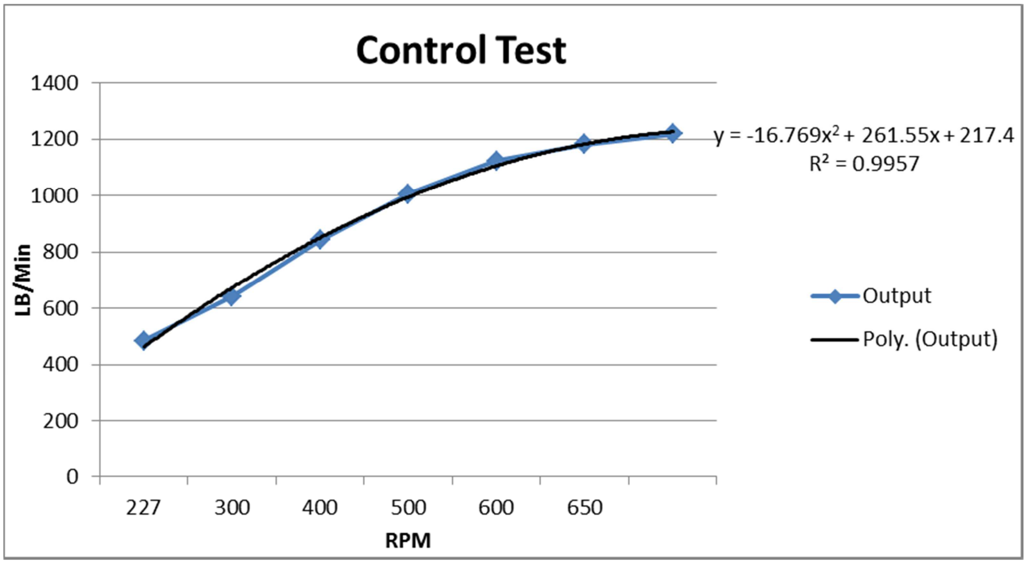
Option seven only pertains to the six inch auger. The current designs contain a 2 7/8” and a 2 3/8” shaft for the 12 inch and 6 inch augers, respectively. We believe that the shaft size on the 6 inch auger is excessively large for the stresses it experiences. If the shaft size is decreased on the same scale as the flighting, a 1 ½” shaft on the 6 inch auger should be sufficient. A smaller shaft will provide more area for proppant to fill inside the auger tube. This will increase the overall output as well as the accuracy at high RPM. Decreasing the shaft size will be difficult to implement on existing FB4K blenders because it requires new flighting in addition to a new shaft. The drive mechanism will also need to be altered to fit the new shaft.

We believe that options one, five, six, and seven fit our design criteria the best. They improve the overall system in several different ways, and do not have many issues with implementation. The concave flighting will increase the durability of the auger. Less wear on the auger will save money that would otherwise be spent on repairs. The concave flighting will slighytly increase the output at all RPMs, and will combat centrifugal force that might throw the proppant into the gap between the flighting and tube at high RPMs. The concave flighting will have a smaller shaft, part of the option seven design. The part of the auger housing that exetends into the hopper will also be removed. A combination of the smaller shaft, tube removal, and Ultra Flyte flighting will result in a higher range of linear output.

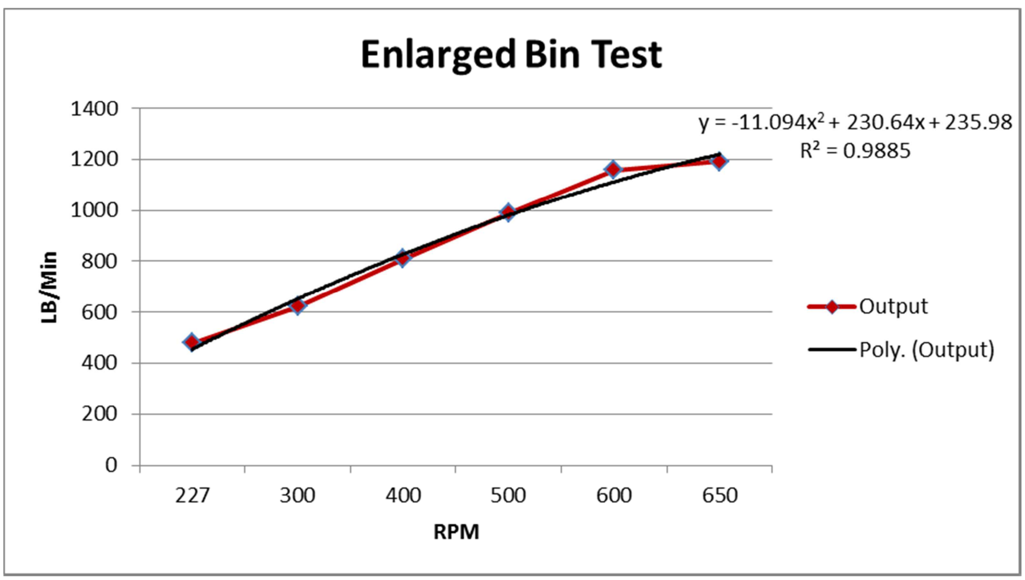
We planned to test each viable option independently, then test combinations of each option. Unfortunately, we did not have time to test combinations during the spring semester. Also, we were not able to test the concave flighting design. Due to the small length of flighting on the six inch auger, the flighting design is not an issue with the output. We do believe that altering the flighting on the twelve inch auger will show a positive effect on output at all RPMs.

Test Results

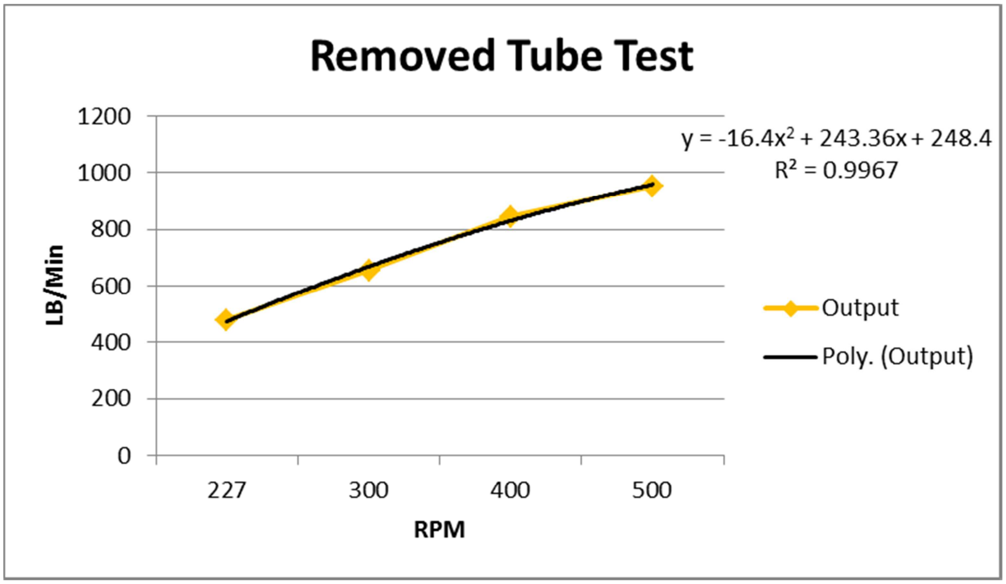
We carried out three tests, control test, testing with a larger bin and testing without inner tube. The first test was the control test. This test gave us data from Halliburton’s original design and allowed us to compare our data from the changes we made. Next, we attached a larger bin to the auger and used the same testing procedures as the control. For the final test, we removed the inner tube and attached the original bin.



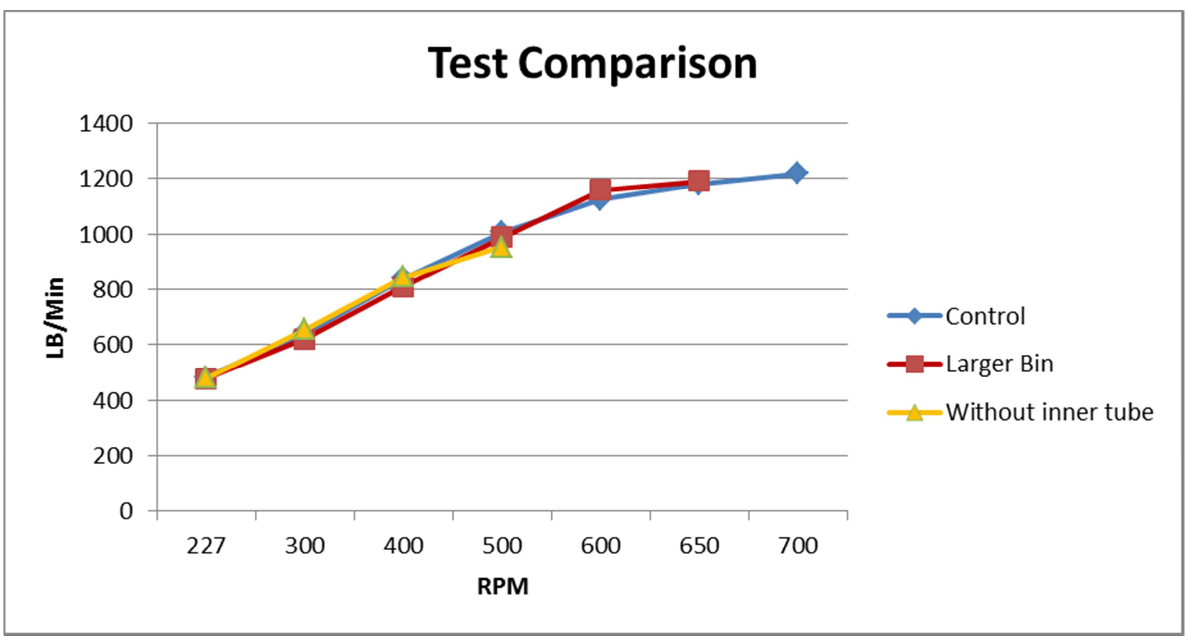
The control tests showed a similar output to the test data that Halliburton provided us with. We were able to run the tests beyond the linear range of operation. This showed us that the auger's output becomes nonlinear after reaching 500 RPMs.



The larger bin did not change the output at the higher RPMs. Our data went into the non linear range, like the control. Even though the larger bin aloud more sand to surround the auger, the output was the same.



When we removed the tube in the bin, we saw outputs that were very similar to our control data. We had an incident while testing that made us unable to take anymore tests past 500 RPMs. During testing procedures, a super sack ripped falling on the auger. The auger then tipped over, and the auger landed on a hydraulic hose. The hose was damaged and would not hold pressure. During tests we discovered that without the tube, the auger has too much weight on it for the motor to turn. The tube also delays back feeding of the auger. Even though we did not reach the RPMs of the nonlinear range, the results were showing the same trends as the previous tests.



Results Anylasis

The results from our testing showed that the larger bin and removing the tube did not affect the nonlinear range. We were not able test altered flighting. It would have needed to be a special order and they require purchase one thousand feet of flighting. With a six inch auger and the 2 3/8in shaft design, UltraFlyte said you would not see an increase in output. This design does not allow enough area of flighting for UltraFlyting to be effective. Our recommendation for Halliburton is to explore changes in flighting. A concave flighting design or a lip on the edge of the flighting, could account for the centrifugal force on the sand.

See Appendix A for TableCurve equations that describe the output of the augers beyond the linear range. We recommend these equations for implementation into the current design for both the twelve inch and six inch conveyors.

Project Management

The project is managed using Microsoft Project software. The project management software program allows us to develop an overall plan by scheduling tasks, assigning resources to those tasks, managing the budget for the resources, and splitting up the workload for the tasks. Tasks range in significance from “optimizing auger output” to “comparing equations.” The program allows us to account for every task required for the completion of this project, no matter how big or small the task may be. This program has proved to be very valuable in scheduling the timetables for our deliverables.

Deliverables

The deliverables for this project are divided into two sections: fall and spring. In the fall, we were given test data from Halliburton to analyze. After analyzing this data, we will deliver an equation for a best fit line for the test data. We will also propose multiple design concepts that could possibly correct the nonlinearity region of the data. We will then present our findings and designs.

In the spring, we will manufacture a prototype of a finalized design and conduct tests on the prototype. The tests will be conducted similar to the original testing done by Halliburton. The new test data will be analyzed and compared to original test data. A new equation will be derived from the new data to be compared to the original equation.

Budget

We have been provided with some monetary assistance for this project directly from Halliburton. They would like to keep the budget between $5-10k. From this we will purchase the necessary equipment to manufacture a scaled working replica of Halliburton's current design with some modifications that will linearize the output of their design. If our experiments prove to be successful, the investment in our research will provide Halliburton with data that suggests how they can improve their fracking process. The improvements will make their process more efficient and profitable. For more details, see Appendix G.

Cost Analysis

We were paired with three Agriculture Economics students to help us analyze the financial benefits of our research. Becca Baca, Chris Willis, and Aaron Hoerst (Oil Field Research Group) provided us with the following cost analysis:

"Given our $10,000 budget, OFCG has estimated the feasibility of optimizing the sand screws on a hydraulic fracture blending system. We have used the cost and amount of proppant saved as a measure of return on investment. With the incorporation of our optimized system according to Halliburton's implementation plan, there is no additional variable cost which may include implementation, labor, and/or maintenance. We have assumed that Halliburton's field operations perform at a level competitive with industry averages, and that the optimized system designed by our engineers will be capable of saving a given percentage of the excess proppant used in the fracturing process.

The engineering team is designing a single sand screw intended to increase the accuracy of proppant introduced into the blending system. A spreadsheet created by the business team allows us to input the estimated price of frac sand; the percent of frac sand saved from using the optimized sand screw; and the amount of frac sand used in a specific well, which ultimately exhibits the cost savings from implementing the enhanced sand screw. The excel spreadsheet also permits Halliburton to enter the exact amount of research and development that was spent on enhancing the sand screw. With this information, along with the depreciation expense per year, we were able to determine the return on investment, the initial investment and the

	A	B	C	D	E	F	K	L	M	N
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2	FORWARD TO DEPRECIATION									
3	FORWARD TO OPERATIONS SUMMARY									
4	FORWARD TO RETURN ON INVESTMENT									
5	BACK TO INTRODUCTION									
6										
7										
8										
9	INPUT CAPITAL STRUCTURE AND			INPUT PRODUCTS, INITIAL VOLUME, MARGIN PER UNIT AND						
10	EXPENSE INFORMATION			ANTICIPATED PROPPANT SAVINGS GROWTH			Research and Development			
11	Other			Product Name	Sand Screw		Product	FC/unit		
12	Expense Inflation Rate	1.00%		Units	Pounds		Sand Screw	$ 5,000		
13	Output price inflation rate	1.00%		Price of Proppant per Pound	$ 5.00					
14	Discount rate for NPV calculation	4.00%		Proppant Used in Well (250k-1mil. 50,000 increments)	350,000					
15				Input Value For Percent of Proppant SavedSaved	3	0.2%				
16	Corresponding Input Value	% of Proppant Saved		Initial Proppant Saved	700					
17	2	0.1%		$ Amount Saved/Well	$ 3,500					
18	3	0.2%								
19	4	0.3%								
20	5	0.4%								
21	6	0.5%								
22	7	0.6%								
26	8	0.7%								
27	9	0.8%								
28	10	0.9%								
29	11	1.0%								

Figure 7: Cost Analysis input values and savings per well **Source: OFCG Cost Analysis Spreadsheet**

percentage of proppant cost saved. We can also estimate the net present value, internal rate of return and payback period of optimizing the blending system. Payback period will be calculated in jobs per blender rather than years.

For example, we can predict the enhanced system will save 0.2% of proppant per well, an average of 350,000 pounds of proppant used per fracture, and the cost of proppant at $5.00 per pound. Using these numbers and a selected discount rate of 4.00%, we have calculated a savings of $3,500 per fracture, on proppant cost alone. These variables can be adjusted as Halliburton sees fit.

Halliburton's budget for prototyping (research and development), which will be the investment cost, cannot exceed $10,000. In this example, we use $5,000.

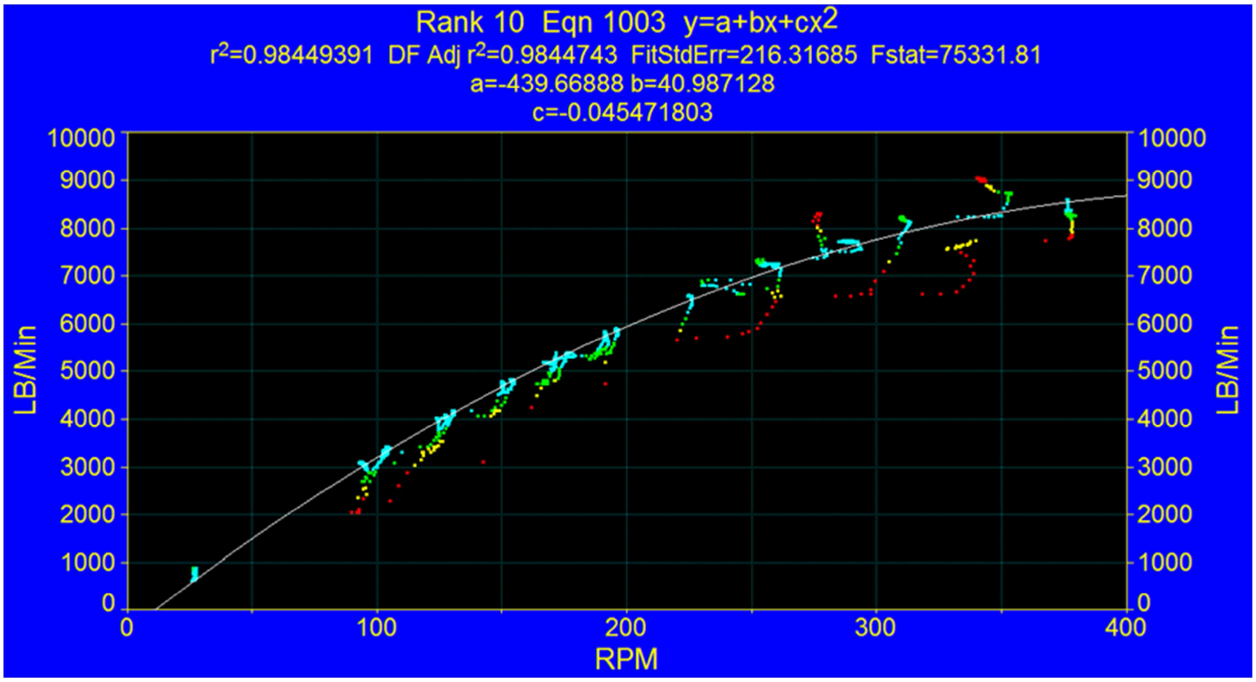
Using an initial investment of $5,000, and proppant values as stated above, the net present value of this project given a 5 fracture analysis is $10,884. The investment would be paid back in less than two years, given the savings as calculated in Figure 7. The profitability of investment, or internal rate of return, is 64.96%."

	A	B	C	D	E	F	G	H
1	MENU							
2	BACK TO INPUTS							
3	BACK TO OPERATION SUMMARY							
4								
5	This sheet summaries the feasibility of the project. It provides net present value, benefit cost ratio and internal rate of return							
6	The only input is the discount rate.							
7								
8	Discount Rate	4.00%						
9								
10	Year		0	1	2	3	4	5
11	Gross Margin			$3,500	$3,535	$3,570	$3,606	$3,642
12	Discount Factor		1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
13	PV of Income		$0	$3,365	$3,268	$3,174	$3,082	$2,994
14								
15	Total Expense		$5,000	$0	$0	$0	$0	$0
16	Less Depreciation and Term Interest			$0	$0	$0	$0	$0
17								
18	Cash Expenses		$5,000	$0	$0	$0	$0	$0
19	Discount Factor		1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
20	PV of Expenses		$5,000	$0	$0	$0	$0	$0
21								
22	Benefits Less Costs		($5,000)	$3,500	$3,535	$3,570	$3,606	$3,642
23	PV Benefits Less PV Costs		($5,000)	$3,365	$3,268	$3,174	$3,082	$2,994
24								
25	Total PV of Income	$15,884						
26	Total PV of Expenses	$5,000						
27	Net Present Value	$10,884						
28	Internal Rate of Return	64.98%						
29	PV Benefit/PV Cost Ratio	3.18						
39	Payback Period (years)	1						
40	(payback period only displayed if less than 10 years)							

Figure 8: Cost Analysis cash flows and projects acceptance calculations, assuming an initial investment of $5,000 **Source: OFCG Cost Analysis Spreadsheet**

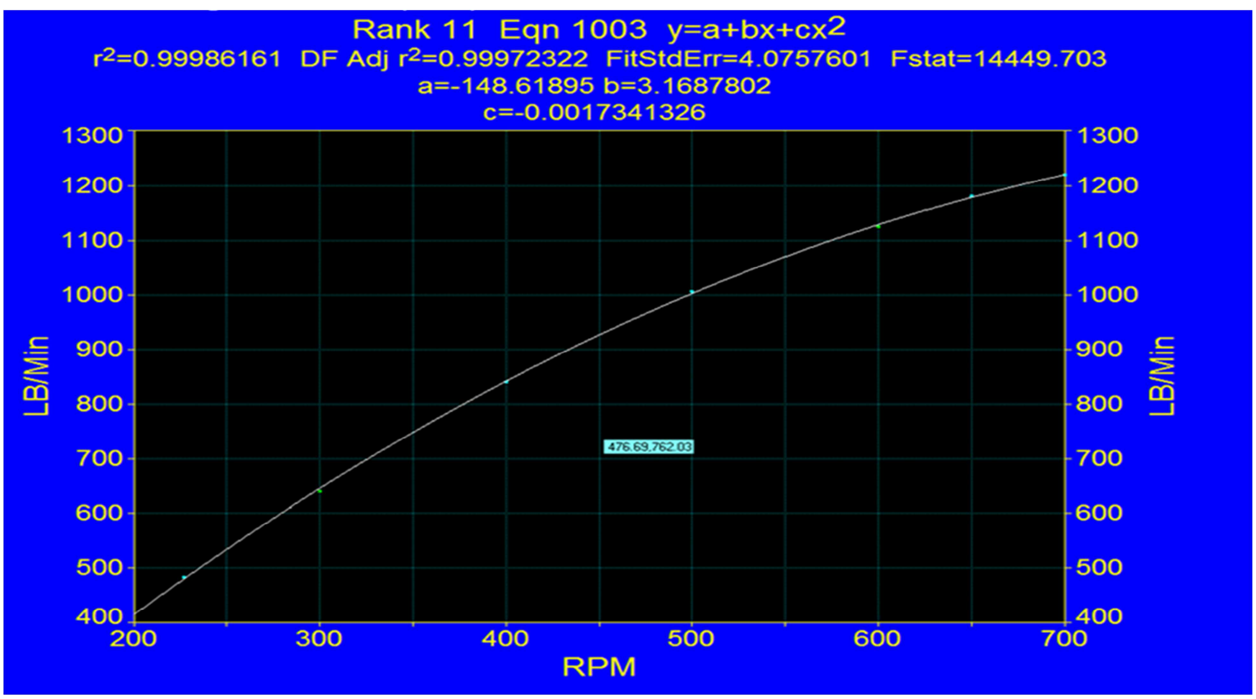
Appendix A: Curve Equations

For 12” auger: $y = -439.67 + 40.99x - 0.0455x^2$

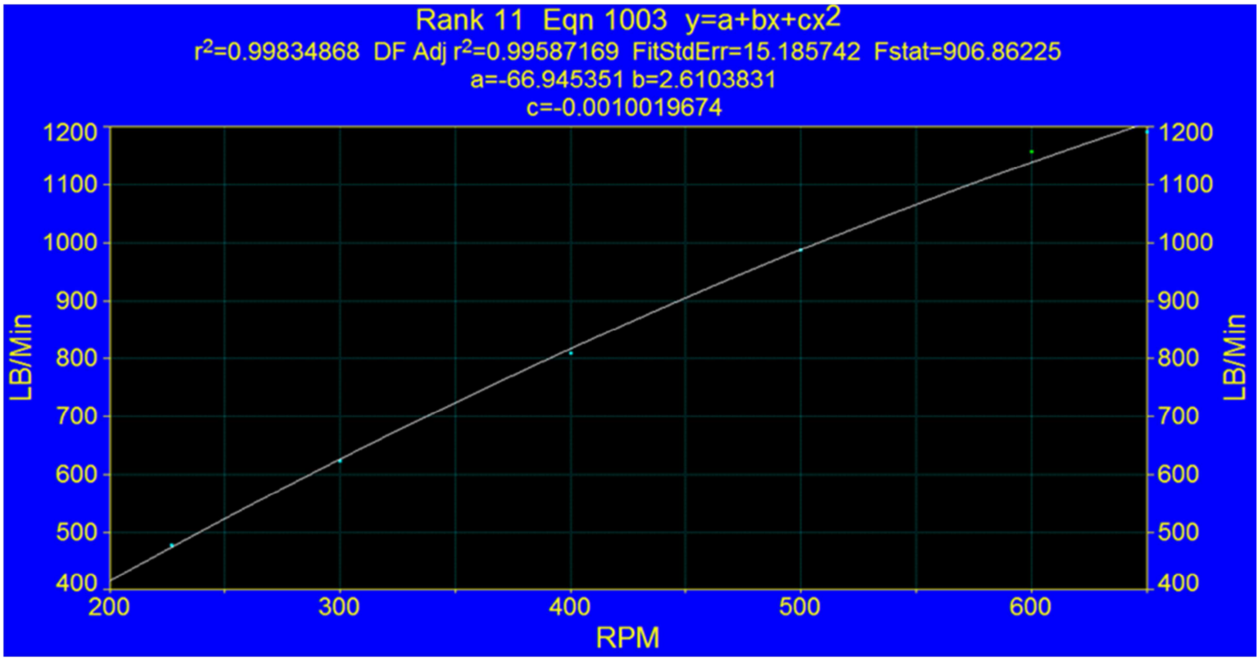


For 6” auger:

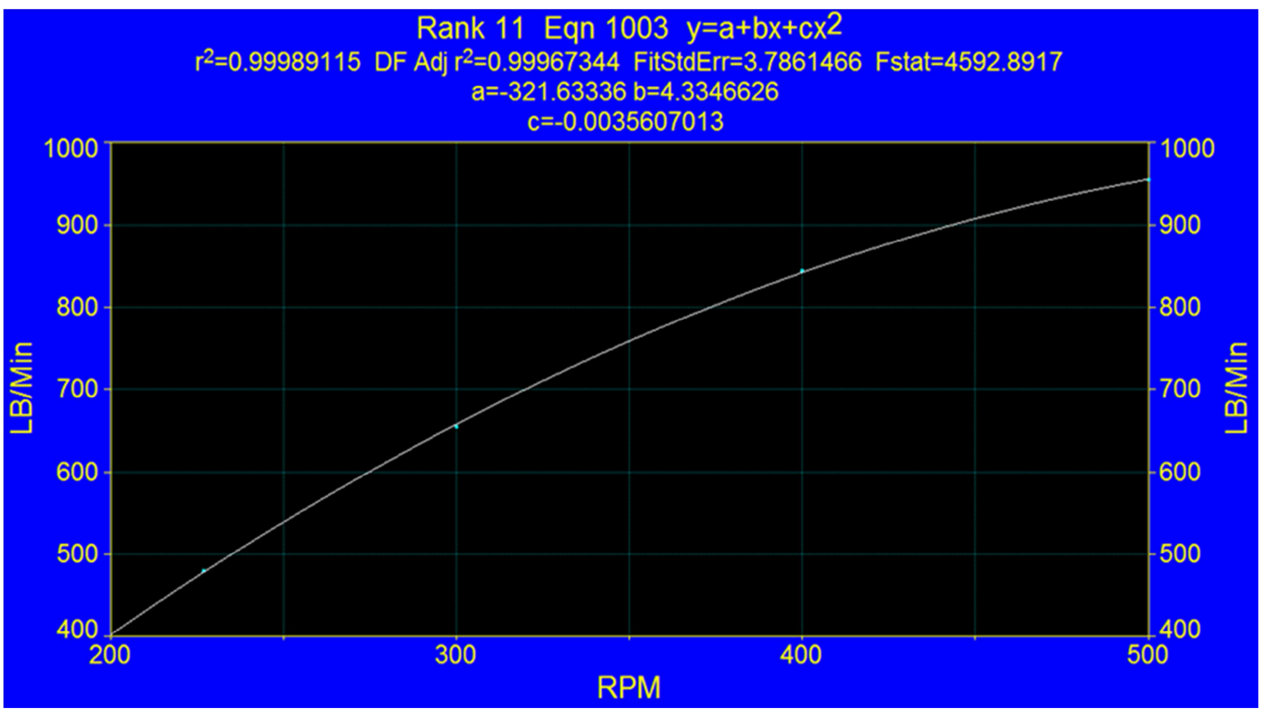
Control : $y = -148.6 + 3.17x - 0.0017x^2$



Enlarged Bin: $y = -66.95 + 2.61 - 0.001x^2$



Removed Tube: $y = -321.63 + 4.33x - 0.0036x^2$



Appendix B: Patents

US006193402B1

(12) **United States Patent**
Grimland et al.

(10) **Patent No.:** **US 6,193,402 B1**
(45) **Date of Patent:** **Feb. 27, 2001**

(54) **MULTIPLE TUB MOBILE BLENDER**

(76) Inventors: **Kristian E. Grimland**, 37279 Timber Dr., Elizabeth; **Timothy Lloyd Anderson**, 20031 Road 17, Fort Morgan, both of CO (US) 80701

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/165,649**

(22) Filed: **Oct. 2, 1998**

Related U.S. Application Data

(60) Provisional application No. 60/077,170, filed on Mar. 6, 1998.

(51) **Int. Cl.**^{7} **B01F 15/02**

(52) **U.S. Cl.** **366/14**; 366/27; 366/33; 366/165.5

(58) **Field of Search** 366/10, 14, 15, 366/27, 28, 33, 34, 42, 165.3, 165.5, 181.6, 606; 166/177.5, 90.1

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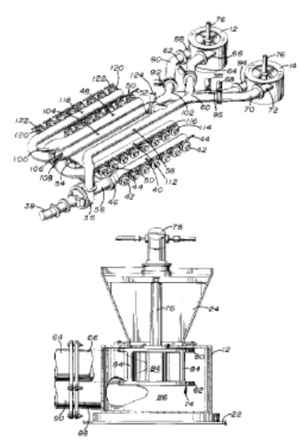
Primary Examiner—Tony G. Soohoo
(74) *Attorney, Agent, or Firm*—Pittenger & Smith, P.C.

(57) **ABSTRACT**

An improved oil and gas well servicing apparatus for blending and delivering a slurry of fracturing fluid and particulate matter at constant flow rate and pressure to a downhole pump is disclosed. Multiple blending tubs are mounted on a trailer or skid and are manifolded together in a slurry discharge manifold. The slurry discharge manifold combines the slurry discharged by the blending tubs and incorporates pipe sections of equal length to connect the blending tubs to the manifold. It is believed that the slurry discharge manifold and equal length piping provide balanced pressure drop between the individual blending tubs and creates a constant outlet pressure from the slurry discharge manifold. A fluid intake manifold may also be included to distribute fracturing fluid to the blending tubs. Hose connectors on each of the manifolds are provided on both sides of the apparatus for convenient operation from either side. A conveyer system delivers particulate matter, such as sand, to a distribution bin located above the blending tubs. A source of fracturing fluid may be attached to a hose connector on the fluid intake manifold. The blending tubs utilize a variable drive means placed above each blending tub and suspending an impeller in the blending tub and rotating it about a vertical axis. Thus, a plenum space is provided between the impeller and the bottom of the tub. A tangential outlet is located adjacent to the plenum space and carries the slurry out of the blending tub and into the slurry discharge manifold.

18 Claims, 6 Drawing Sheets



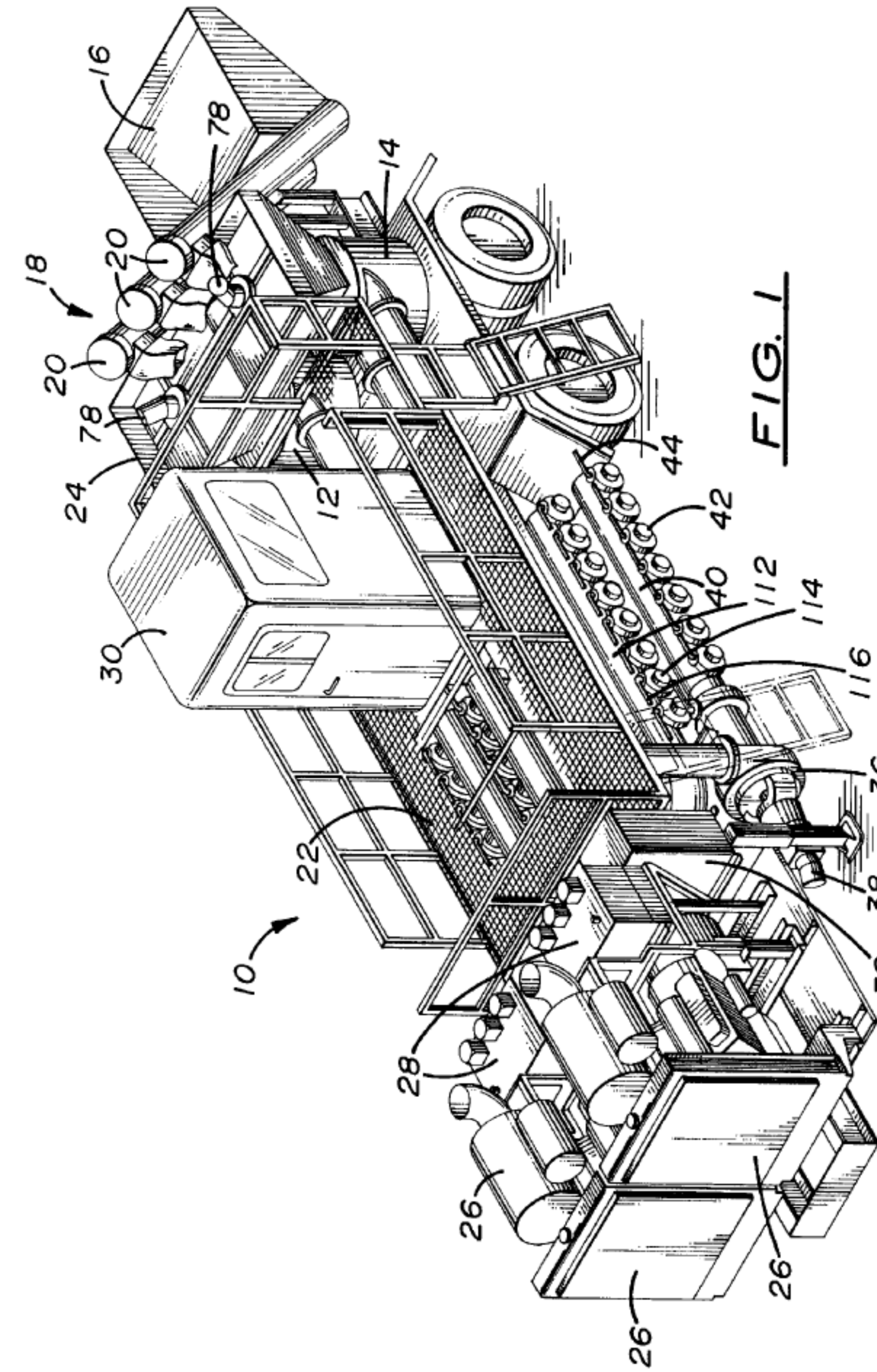

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FIG. 1

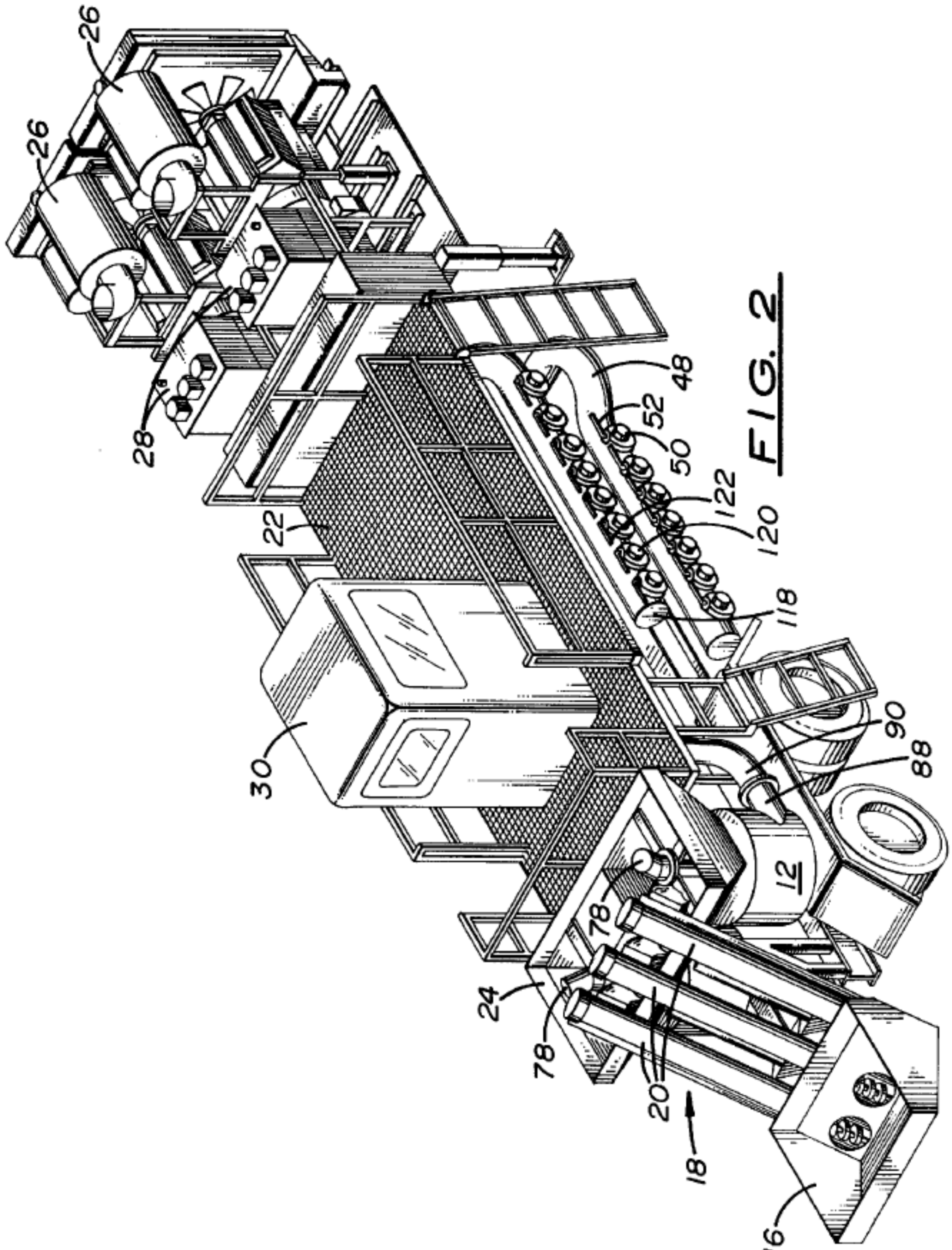

FIG. 2

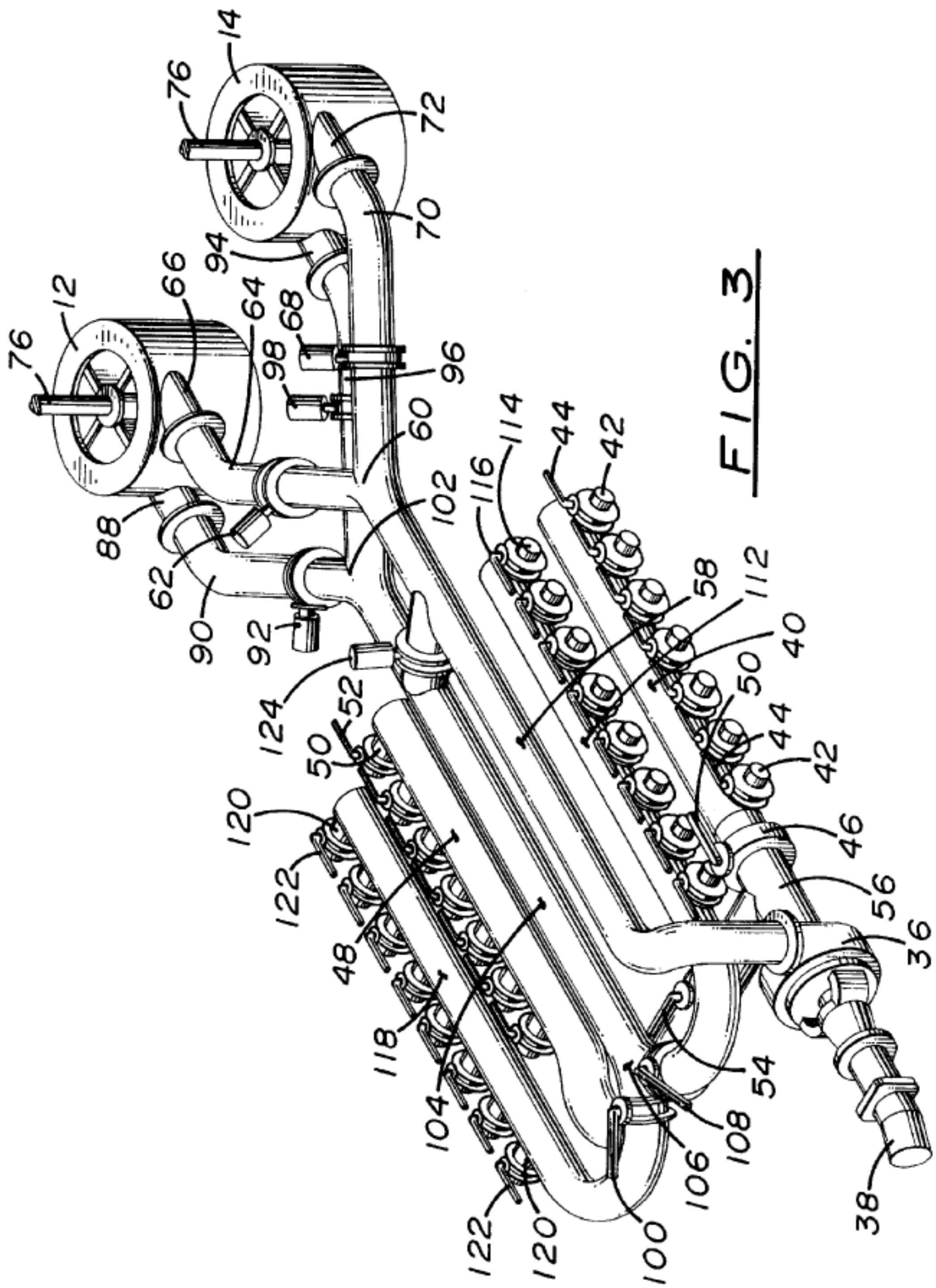
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FIG. 3

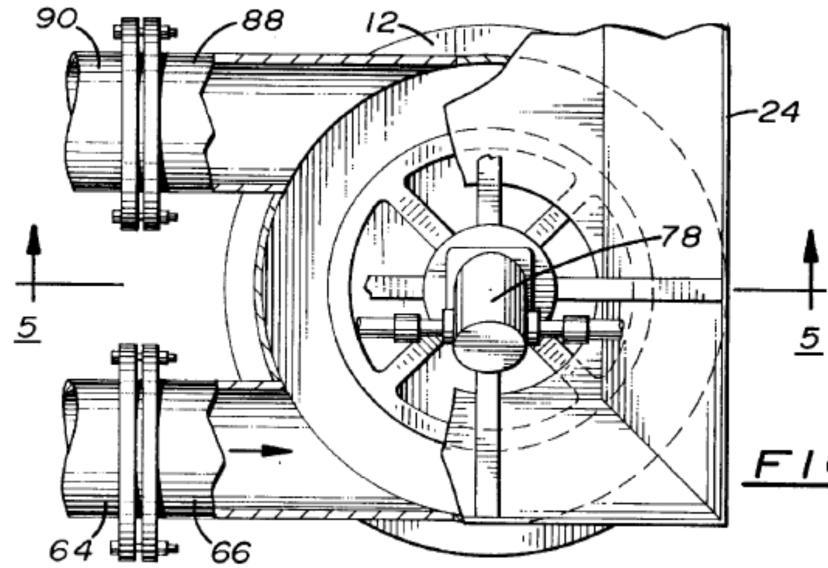

FIG. 4

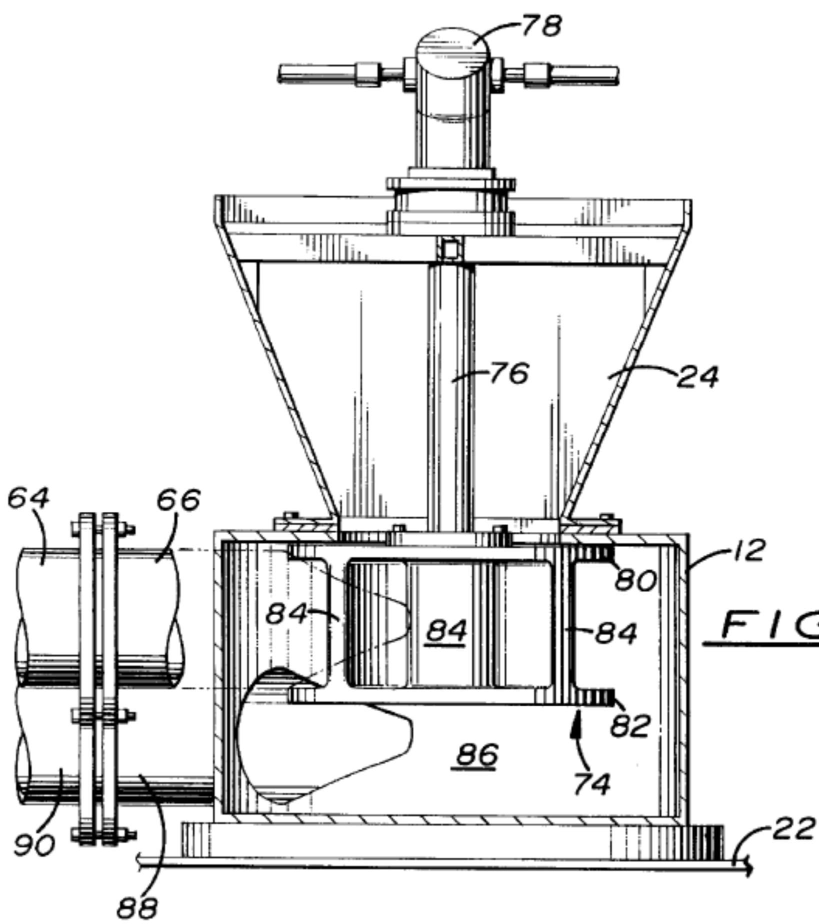

FIG. 5

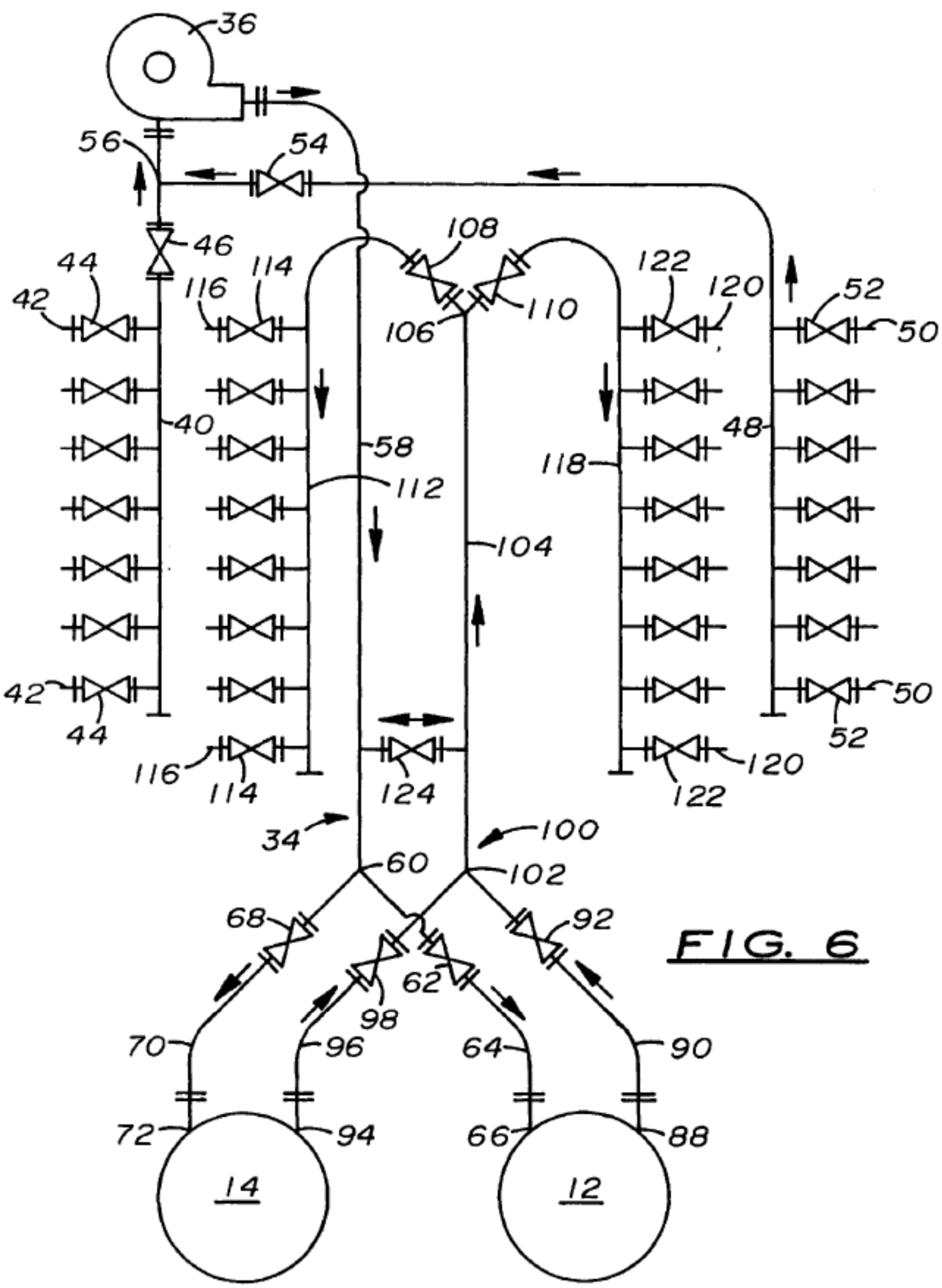
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FIG. 6

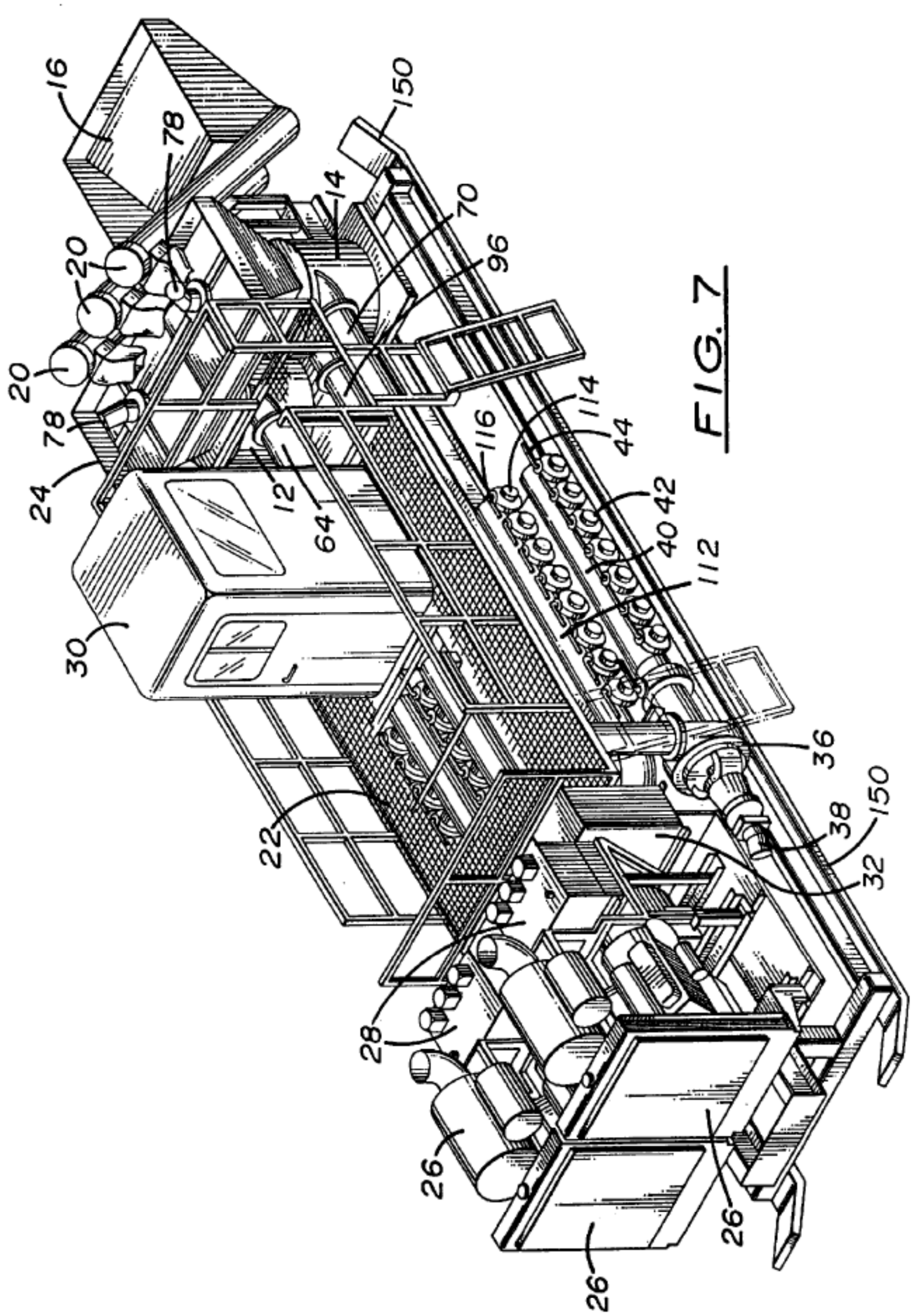
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FIG. 7

Appendix C: Other Company Blender Solutions

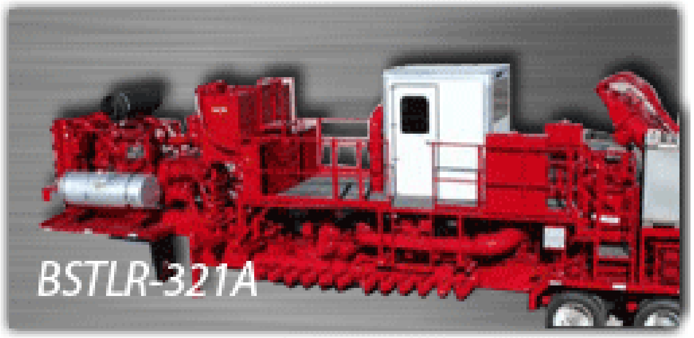
National Oilwell Varco

MT-1060 Blender equipped with eight (8) precision chemical metering systems

Features:

- Trailer Mounted
- Max rate operating configurations froms 60 BPM to 100 BPM
- Up to eight chemical systems (dry or liquid) acailable with variety of styles and delivery rates available
- Choice of twin or triple proppant augers in several available configurations and sizes
- Fixed or swing out auger systems

Serva Group



BSTLR-321A Blender

Features:

- Trailer Mounted
- Fluid Rate – 120 bpm
- Two 12” and one 6” auger hydraulically driven
- Four liquid additive pumps, hydraulically driven

Jereh

Jereh HST360 Blender

Features:

- Trailer Mounted
- Two 12” and one 8” screw conveyors
- Max Sand convey rate: 12,713 ft^3/hr
- Max discharge flowrate: 125 bbl/min
- Max sand density: 150 lb/ft^3

Tarcom


Tarcom Blender II

Features:

- Single man operated grom climate controlled cabin
- Powered by 460 hp truck engine
- Data Acquisition System able to record and display up to 200 parameters in real time from different rates, temperatures, and pressures.

NRG Manufacturing

1320 Blender

Features:
- Two 12” augers and one 6” auger.
- 12” augers deliver up to 9500 lb/min
- 6” augers deliver 4000 lb/min
- Includes automatic grease dispensing system to provide lubricant to the lower bearings

Fracturing Blenders

Stewart & Stevenson's fracturing blenders provide industry-leading job performance and reliability. Our blenders allow operators to mix complex fracturing slurries with varying densities for the most demanding treatments.

Stewart & Stevenson's AccuFrac System provides automated density and chemical controls in a user-friendly interface from the unit or data van. The unique concentric mixing chamber provides accurate and homogenous proppant mixing at both low and high rates without air entrainment. Highly efficient closed loop hydraulic systems provide faster response than open loop systems, while consuming less power and producing less waste heat for longer component life and reduced maintenance requirements.

MS-60 Skid mounted blender.

MT-132 Trailer mounted fracturing blender.

MC-60 Bodyload fracturing blender for extreme cold weather operations.

MT-102 Trailer mounted fracturing blender.

MC-60 Bodyload fracturing blender with closed chamber mixing system.

6

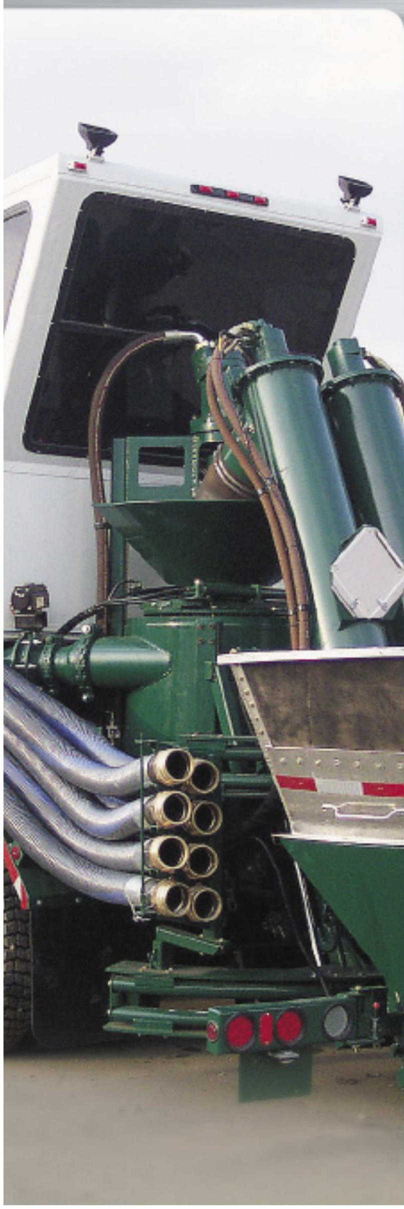
MT-132 Trailer mounted fracturing blender.

STEWART & STEVENSON FRACTURING BLENDERS						
MODEL	MT-132 Trailer Mounted Blender	MT-102 Trailer Mounted Blender	MC-100 Bodyload Blender	MC-60 Bodyload Blender	MS-60 Skid Mounted Blender	MS-30 Skid Mounted Blender
Maximum Discharge Rate	130+ bbl/min	100 bbl/min	100 bbl/min	60 bbl/min (75 bbl/min optional)	60 bbl/min	30 bbl/min
Maximum Discharge Density	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal
Maximum Proppant Input Rate	21,250 lb/min (optional higher rates available)	21,250 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	6000 lb/min (optional higher rates available)
Carrier Type	Stewart & Stevenson trailer	Stewart & Stevenson trailer	Kenworth, Mercedes Benz or other truck chassis	Kenworth, Mercedes Benz or other truck chassis	Oilfield Skid	Oilfield Skid
Size: L x W x H	48'0" x 8'6" x 13'6"	48'0" x 8'6" x 13'6"	36'8" x 8'6" x 13'2"	34'8" x 8'6" x 13'2"	24'8" x 8'6" x 12'0"	19'6" x 8'6" x 8'0"
Mixing Chamber	Concentric tub with automatic level control	Concentric tub with automatic level control	Concentric tub with automatic level control	Pressurized mixing chamber or concentric tub	Pressurized mixing chamber or concentric tub	Hydrojet tub
Drive System*	(2) Deck engines	(2) Deck engines	(1) Truck engine and (1) deck engine	(1) Truck engine	(1) Deck engine	(1) Deck engine
Total Horsepower	1550 bhp	1550 bhp	1050 bhp	500 bhp	600 bhp	330 bhp
Number of Liquid Additive Systems	6 or more	6 or more	6 or more	6 or more	6 or more	6 or more
Number of Dry Additive Systems	Up to 2	Up to 2	Up to 2	Up to 2	Up to 2	Up to 2
Discharge Pump	14x12	14x12	14x12	Not Required	Not Required	5x6
Suction Pump	12x12	12x10	12x10	8x10	8x10	5x6
Automated Control System	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac
Cold Weather Package	Optional	Optional	Optional	Optional	Optional	Optional

* Other manufacturers available

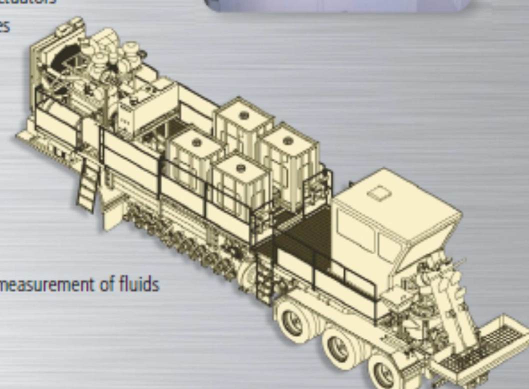
ENERFLOW INDUSTRIES INC.

Frac Blender



Features

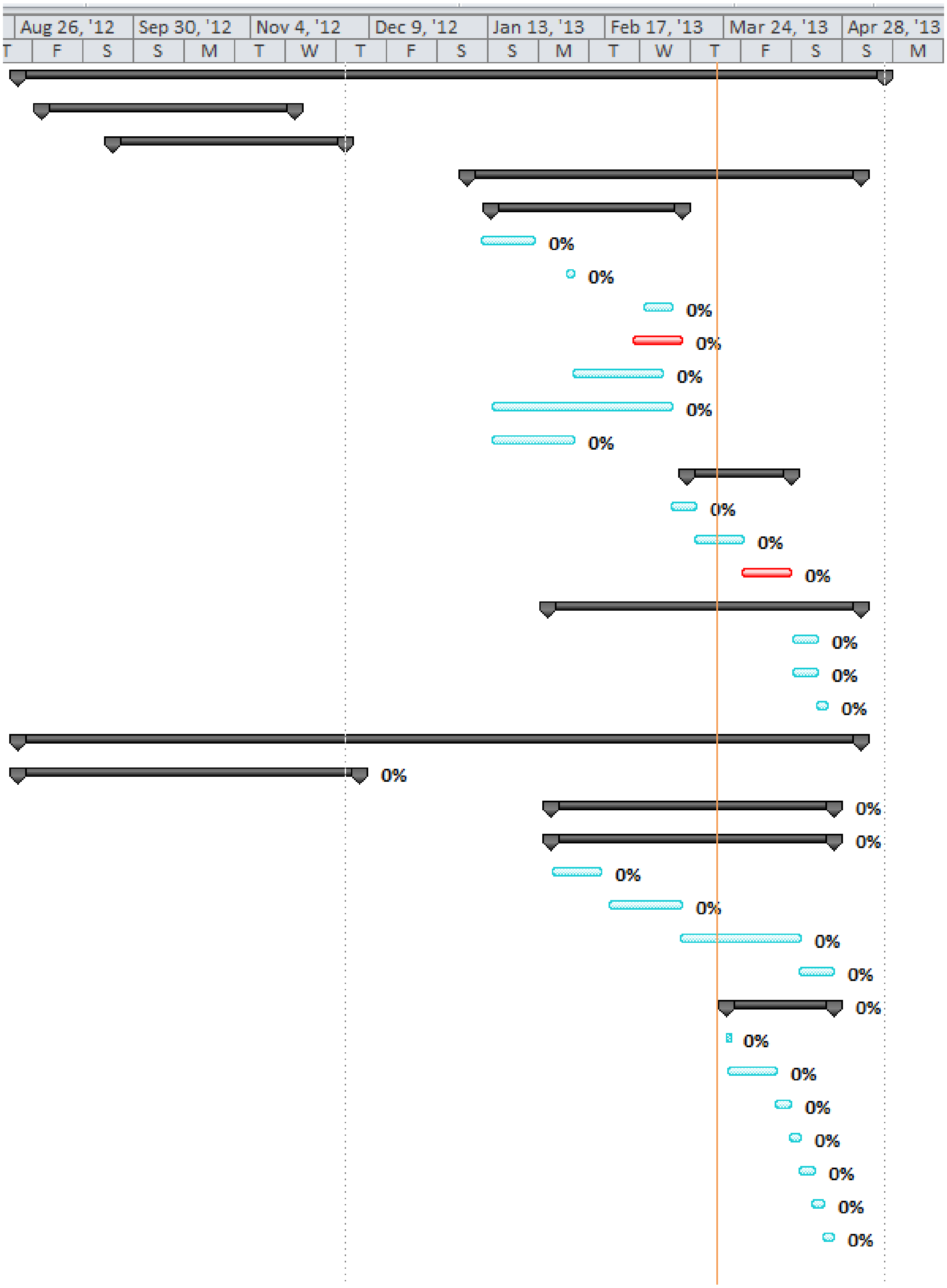
- Truck, Trailer or Skid Mounted
- Engine: Caterpillar, Cummins or Detroit Diesel (various Hp ratings)
- Twin augers
- Mixing tub
- Hydraulically driven mixing systems
- Liquid additive system
- Centrifugal suction pump
- Computer or manually controlled sand augers
- Suction and discharge manifolds on both sides of the unit for ease of rig up
- Suction and discharge manifold flow meters
- Pneumatic remote valve actuators
- Discharge and suction hoses
- Density gauge
- Swing augers
- Chemical transfer pump
- Viscometer
- Chemical totes
- Heated control cabin
- pH meter
- Dry additive systems
- ECAMS™ for control and measurement of fluids



Appendix D: Gantt Chart

Task Name	Duration	Start	Finish
Optimize Auger Output	**185 days**	**Mon 8/27/12**	**Fri 5/10/13**
Produce Equation	**55 days**	**Mon 9/3/12**	**Fri 11/16/12**
Get test data from Halliburton	5 days	Mon 9/3/12	Fri 9/7/12
Analyze data in excel	10 days	Fri 9/7/12	Thu 9/20/12
Analyze data in TableCurve	14 days	Fri 9/21/12	Wed 10/10/12
Evaluate TableCurve equations	27 days	Thu 10/11/12	Fri 11/16/12
Choose best equation	1 day	Fri 11/16/12	Fri 11/16/12
Redesign equipment	**51 days**	**Mon 9/24/12**	**Sat 12/1/12**
Make SolidWorks drawing of 6" auger	15 days	Mon 9/24/12	Fri 10/12/12
Analyze current design shaft stresses	28 days	Mon 9/24/12	Wed 10/31/12
Generate redesign options	32 days	Fri 10/12/12	Mon 11/26/12
Choose best design options for prototypes	32 days	Fri 10/12/12	Mon 11/26/12
Prototype Testing	**85 days**	**Mon 1/7/13**	**Fri 5/3/13**
Acquire Equipment	**41 days**	**Mon 1/14/13**	**Mon 3/11/13**
Assemble Bill of Materials	12 days	Fri 1/11/13	Sat 1/26/13
Get Halliburton Auger	3 days	Tue 2/5/13	Thu 2/7/13
order auger flighting	7 days	Thu 2/28/13	Fri 3/8/13
make sheet metal bin hoppers	11 days	Mon 2/25/13	Mon 3/11/13
proppant	19 days	Thu 2/7/13	Tue 3/5/13
Test stand	40 days	Mon 1/14/13	Fri 3/8/13
test site	19 days	Mon 1/14/13	Thu 2/7/13
Testing	**23 days**	**Wed 3/13/13**	**Fri 4/12/13**
Set up equipment	6 days	Fri 3/8/13	Fri 3/15/13
run control test	11 days	Fri 3/15/13	Fri 3/29/13
change variables	11 days	Fri 3/29/13	Fri 4/12/13
Results	**67 days**	**Thu 1/31/13**	**Fri 5/3/13**
analyze test results	7 days	Sat 4/13/13	Sat 4/20/13
produce equation that describes new prototype output	7 days	Sat 4/13/13	Sat 4/20/13
compare prototype equation with current design equation	3 days	Sat 4/20/13	Tue 4/23/13
Report	**180 days**	**Mon 8/27/12**	**Fri 5/3/13**
Fall Semester	**73 days**	**Mon 8/27/12**	**Wed 12/5/12**
Written report	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	10 days	Mon 8/27/12	Fri 9/7/12
write first draft	66 days	Mon 8/27/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize report	2 days	Mon 12/3/12	Tue 12/4/12

powerpoint	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	35 days	Mon 8/27/12	Fri 10/12/12
create first draft	32 days	Fri 10/12/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize presentation	2 days	Mon 12/3/12	Tue 12/4/12
Oral Presentation	**3 days**	**Mon 12/3/12**	**Wed 12/5/12**
practice presentation	1 day	Tue 12/4/12	Tue 12/4/12
present final report	1 day	Wed 12/5/12	Wed 12/5/12
Spring Semester	**60 days**	**Fri 2/1/13**	**Thu 4/25/13**
Written report	**60 days**	**Fri 2/1/13**	**Thu 4/25/13**
Select outline	11 days	Fri 2/1/13	Fri 2/15/13
Write First Draft	16 days	Mon 2/18/13	Mon 3/11/13
edit first draft	26 days	Mon 3/11/13	Mon 4/15/13
finalize report	9 days	Mon 4/15/13	Thu 4/25/13
powerpoint	**24 days**	**Mon 3/25/13**	**Thu 4/25/13**
Select outline	1 day	Mon 3/25/13	Mon 3/25/13
Create first draft	11 days	Mon 3/25/13	Mon 4/8/13
edit first draft	5 days	Mon 4/8/13	Fri 4/12/13
finalize report	2 days	Fri 4/12/13	Mon 4/15/13
preliminary presentation	5 days	Mon 4/15/13	Fri 4/19/13
Finalize presentation	2 days	Fri 4/19/13	Mon 4/22/13
Practice Presentation	4 days	Mon 4/22/13	Thu 4/25/13



Aug 26, '12
Sep 30, '12
Nov 4, '12
Dec 9, '12
Jan 13, '13
Feb 17, '13
Mar 24, '13
Apr 28, '13
T F S S M T W T F S S M T W T F S S M
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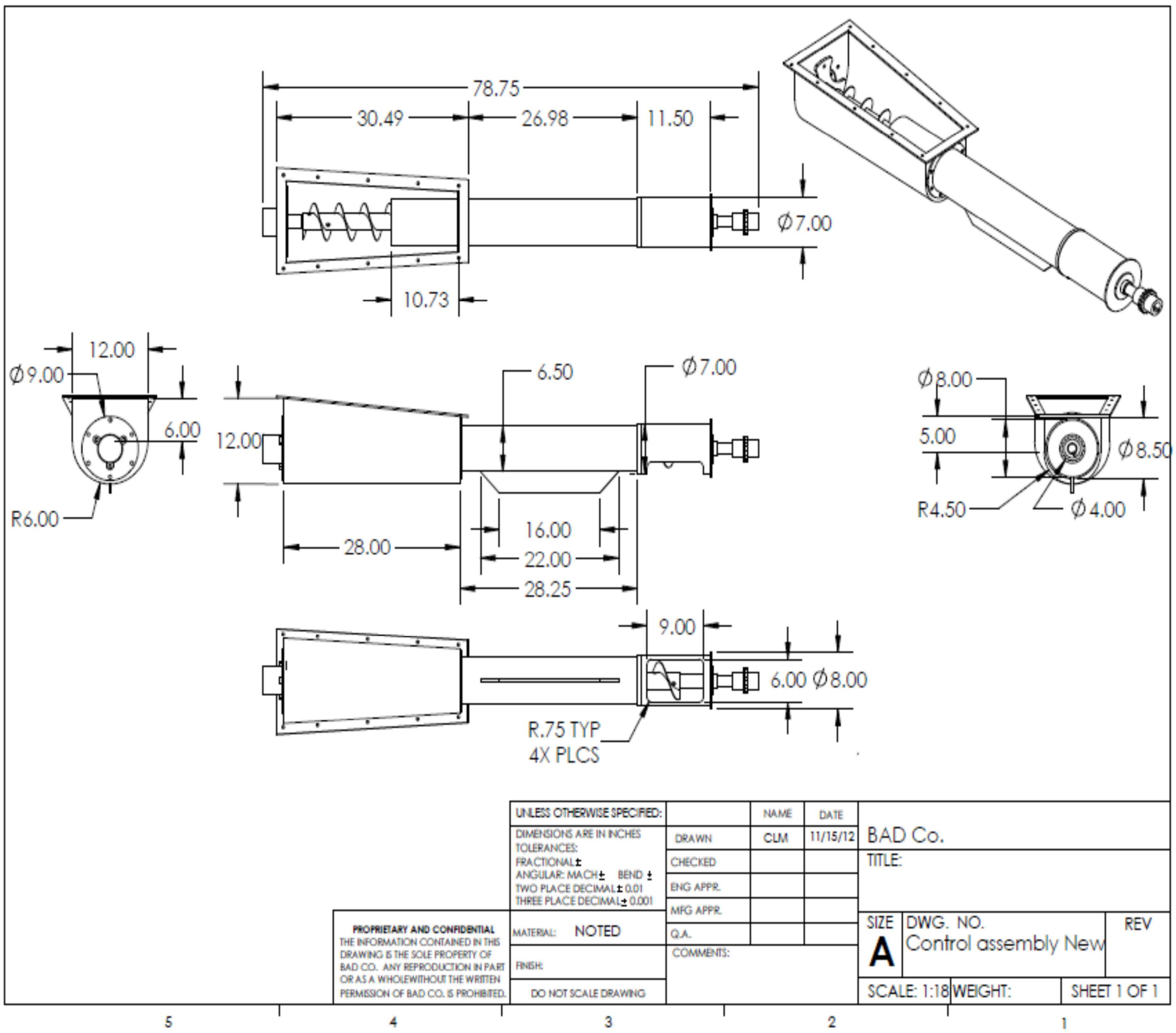
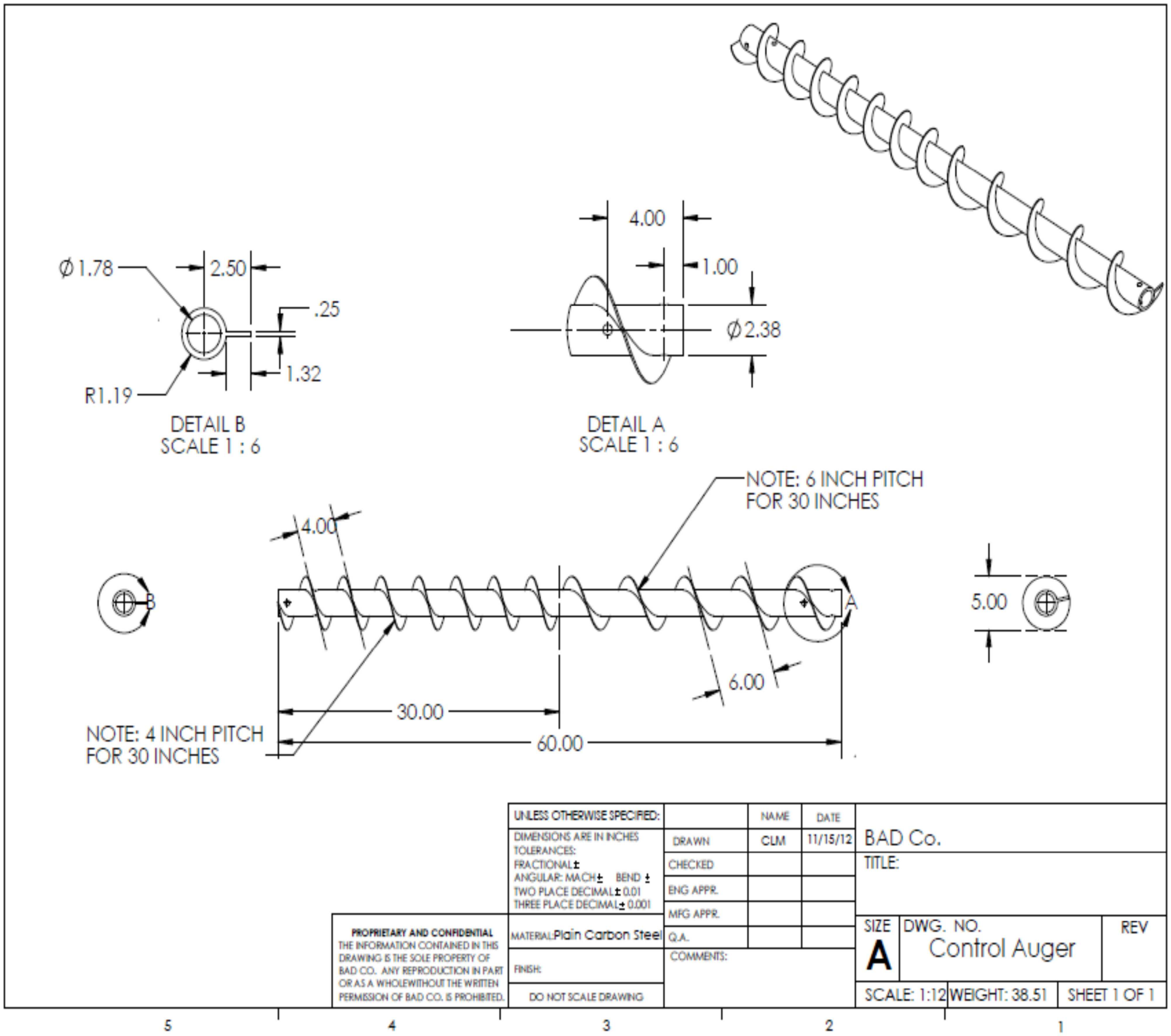
Appendix E: Engineering Drawings

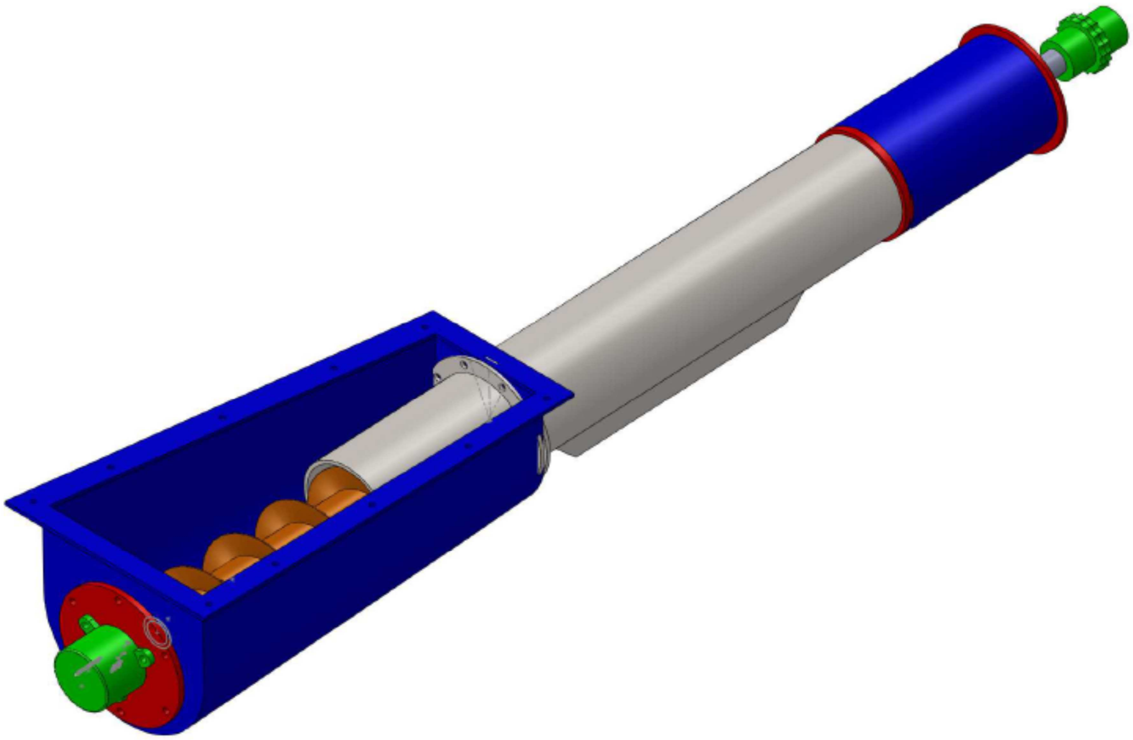
Original Design for Shortened Housing Assembly:



Original Design for Shortened Auger Assembly:



Original Design for Control Assembly:



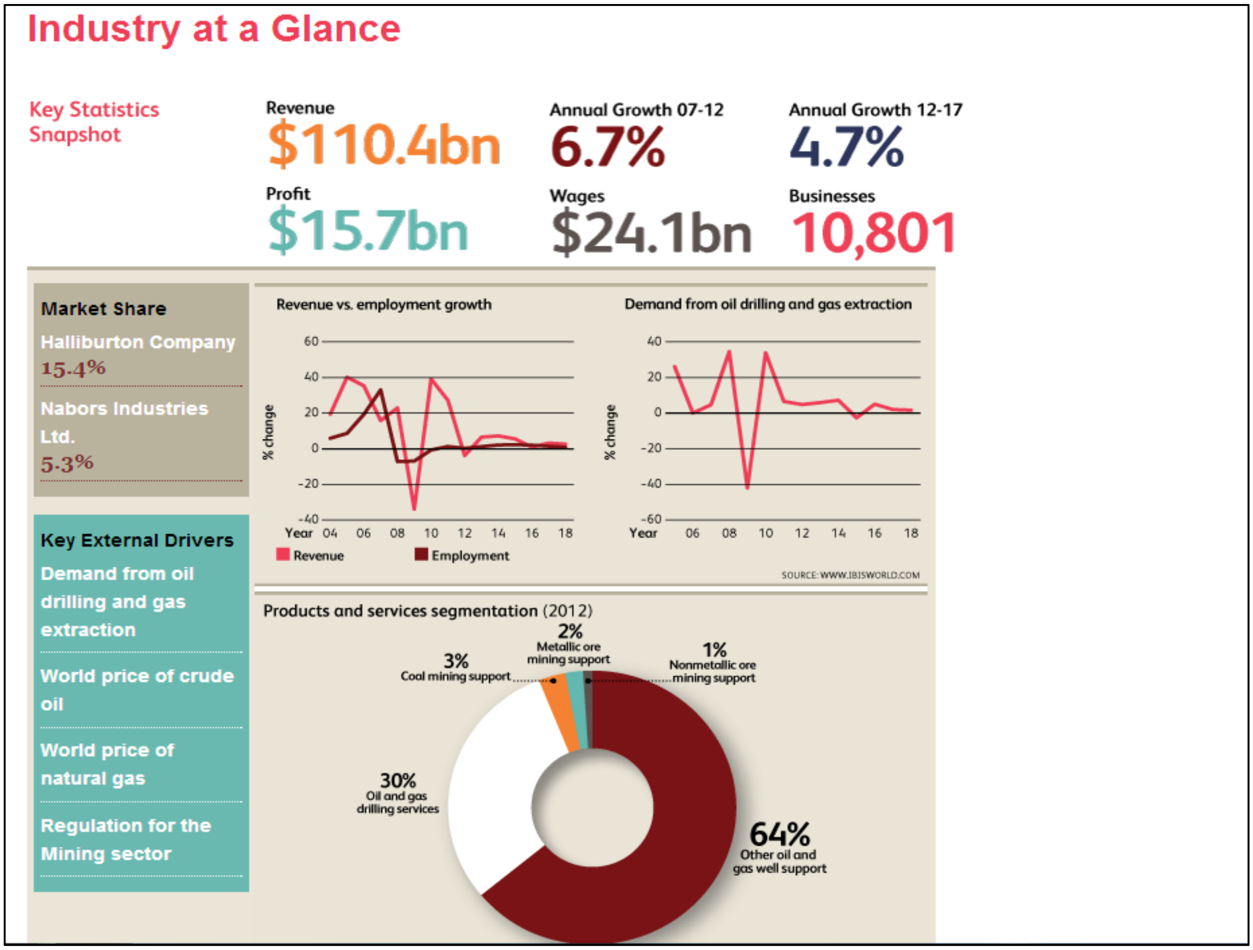
Appendix F: Work Breakdown Structure

1. Optimize Auger Output (100)
    - 1.1. Produce Equation (50)
        - 1.1.1. Obtain testing data in excel (5)
        - 1.1.2. Analyze excel data (5)
        - 1.1.3. Enter data into modeling software (5)
        - 1.1.4. Run simulation (10)
        - 1.1.5. Analyze simulation results (10)
        - 1.1.6. Produce and analyze equation (15)
    - 1.2. Redesign equipment (50)
        - 1.2.1. Analyze Current Auger Shaft Stresses (5)
        - 1.2.2. Decide which part needs redesigned (5)
        - 1.2.3. Create SOLID WORKS drawings of new designs (5)
    - 1.3. Acquire testing equipment and test site (5)
        - 1.3.1. Acquire auger (1)
        - 1.3.2. Acquire proppant from Halliburton (1)
        - 1.3.3. Acquire auger casing and stand (1)
        - 1.3.4. Acquire variable speed drive and power source (1)
        - 1.3.5. Acquire means of measuring output (1)
    - 1.4. Test prototype (15)
        - 1.4.1. Assemble prototype (5)
        - 1.4.2. Set up testing equipment (1)
        - 1.4.3. Run multiple tests (4)
            - 1.4.3.1. Measure proppant output vs RPM (2)
            - 1.4.3.2. Change speed of variable drive and repeat test (2)
        - 1.4.4. Alter prototype (if necessary) and repeat (5)
    - 1.5. Analyze test results (5)
    - 1.6. Create equation that describes output of new prototype (5)

Appendix G: Cost Of Supplies

Payee	Payment
McMaster-Carr	\$686.73
Stillwater Steel & Welding	\$660.60
Napa Auto Parts	\$380.87
BEI Sensors	\$507.00
Brewer Carpet One	\$79.20
Total:	\$2,314.40

Appendix H: Market Research



Appendix J: Screw Conveyors Reference

The following reference was taken from **Engineering Principles of Agricultural Machines 2nd Edition** by Ajit K. Srivastava.

14.1 Screw Conveyors

Augers are used to convey materials that are free flowing, such as grain, as well as difficult fibrous materials and powders. For example, in a grain combine, augers are used to move cut crop on the platform to the feeder housing, clean grain from the bottom of the cleaning shoe to the grain tank, and to unload the grain tank onto a wagon or a truck. Augers are used at grain elevators and farmsteads to load grain storage bins and on feedlots for feed distribution.

14.1.1 Screw conveyor methods and equipment

The *screw conveyor* consists of a shaft that carries helicoid flightings on its outer surface. These flighting are enclosed either in a trough for horizontal augers or in a tube for elevating augers. The tube or the trough is held stationary while the rotation of the flightings causes the material to move longitudinally. Figure 14.1 shows the essential components of a screw conveyor. At the inlet side, the auger flightings extend beyond the tube. Generally, a hopper is provided to hold the material while it is conveyed into the tube. Augers can be permanently installed in a machine, or at a site, or they can be portable. The augers are driven either at the intake side or the discharge side. There are some center-drive augers but they are not common in agricultural applications.

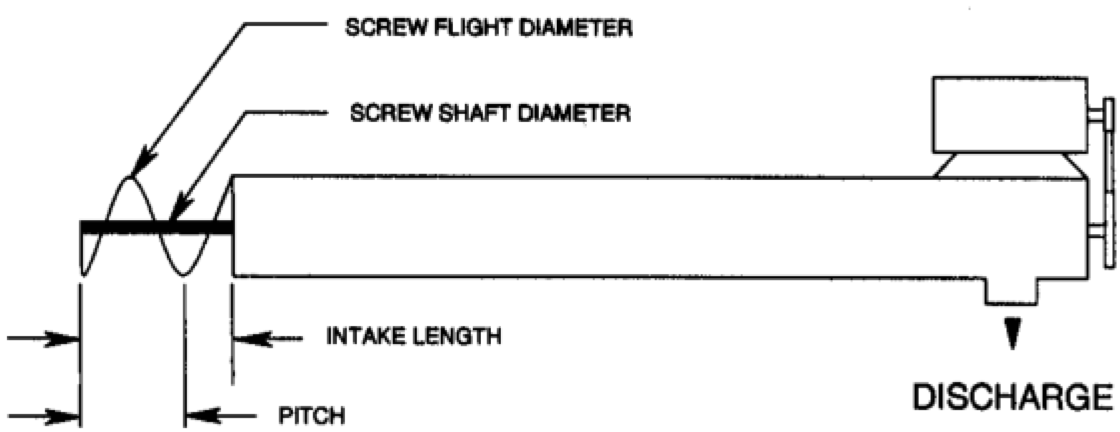


Figure 14.1 - A schematic diagram of a screw conveyor.

The auger length is defined as the length of the tube assembly including any intake but not including the intake hopper and/or the head drive. The intake length is the visible flighting at the intake of the auger. The outside diameter of the tube is referred to as the auger size. A standard pitch auger is the one whose pitch is approximately equal to the outside diameter of the helicoidal flighting. Generally, the pitch is not less than 0.9 and not more than 1.5 times the outside diameter. Standard pitch augers are used for horizontal and up to 20 degrees inclination angles. For inclination angles greater than 20 degrees, half-standard pitch screws are used. Double- and triple-flight, variable-pitch, and stepped-diameter screws are available for moving difficult materials and controlling feed rates.

14.1.2 Theory of screw conveyors

The *theoretical volumetric capacity* of an auger is expressed as:

$$Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n \quad (14.1)$$

where Q_t = theoretical volumetric capacity, m^3/s

d_{sf} = screw flighting diameter, m

d_{ss} = screw shaft diameter, m

l_p = pitch length, m

n = screw rotational speed, rev/s

In reality the actual capacity of an auger is considerably less than the theoretical capacity. This results in loss of volumetric efficiency. The *volumetric efficiency* is defined as:

$$\eta_v = \frac{Q_a}{Q_t} \quad (14.2)$$

where η_v = volumetric efficiency

Q_a = actual volumetric capacity, m^3/s

Generally, the throughput rate in terms of mass (or weight) per unit of time, for example t/h or kg/min, is specified. The volumetric capacity is obtained by dividing the throughput rate by the bulk density of the material.

The power requirement of an auger is expressed by the *specific power*, defined as:

$$P' = \frac{P/L}{Q_a \rho_b} \quad (14.3)$$

where P' = specific power, W s/kg m

P = power requirement, W

L = auger length, m

ρ_b = material bulk density, kg/m ^{3}

Thus, the specific power is the power required to convey a unit mass throughput rate per unit auger length.

The process of conveying by a screw conveyor is complex. It is difficult to develop analytical models to predict volumetric capacity and power requirements without making overly simplified assumptions. Purely empirical models, on the other hand, are not general enough in nature and cannot be used to predict auger performance in a variety of applications. Rehkugler and Boyd (1962) proposed the application of dimensional analysis as a tool to develop a comprehensive prediction model for screw conveyor performance. Table 14.1 shows a list of variables that are pertinent to the problem. These variables can be combined into ratios or dimensionless groups called the pi-terms using Buckingham's Theorem (see Chapter 1). The following equation includes the dimensionless terms:

$$\pi_1 = f\left(\frac{d_t}{d_p}, \frac{d_{sf}}{l_p}, \frac{d_{ss}}{l_p}, \frac{l_i}{l_p}, n\sqrt{\frac{l_p}{g}}, f(\Theta), \mu_1\mu_2\right) \quad (14.4)$$

where $$\pi_1 = \frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n} \quad \text{or} \quad \frac{P/L}{Q_a \rho_b g} \quad (14.5)$$

Table 14.1. A list of variables affecting screw conveyor performance.

Symbol	Variable definition	Dimensions	Units
Q_a	actual volumetric capacity	L^3/T	m^3/s
P	power requirement	ML^2/T^3	W
d_t	tube inside diameter	L	m
d_{sf}	outside screw diameter	L	m
d_{ss}	screw shaft diameter	L	m
L	screw length	L	m
l_p	screw pitch length	L	m
l_i	exposed screw intake length	L	m
n	angular speed	1/T	rev/s
θ	angle of conveyor inclination	-	degrees
ρ_b	material bulk density	M/L^3	kg/m^3
μ_1	material-metal friction	-	-
μ_2	material-material friction	-	-
g	acceleration of gravity	L/T^2	m/s^2

The first term in the right hand side of Equation 14.5 is the ratio of the actual volumetric throughput rate to the theoretical volume swept by the screw per unit of time. This has been regarded as the volumetric efficiency of the screw conveyor. The second term in the right hand side of the above equation is the power required per unit length per unit mass flow rate of the material being conveyed. It has been defined as the specific power or the power efficiency of the conveyor. The conveyor length does not affect the volumetric efficiency.

The dimensionless terms of Equation 14.4 were used to develop prediction equations using experimental data. Published data on the performance of auger conveyors conveying wheat, oats, and shelled corn were used to develop the performance equations. These equations may be used to estimate conveyor performance for similar materials.

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\ l_p n} = \left(4.332\times10^{-4}\right)\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{-0.44}\left(\frac{l_i}{l_p}\right)^{0.31}\left(f_1(\theta)\right)^{1.35}\mu_1^{-4.59}\mu_2^{-3.72} \tag{14.6}$$

$$\frac{P/L}{Q_a\rho_b g} = 3.54\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{0.14}\left(\frac{d_{sf}}{l_p}\right)^{-10.12}\left(\frac{l_i}{l_p}\right)^{0.11}\left(f_2(\theta)\right)\mu_2^{2.05} \tag{14.7}$$

where $f_1(\theta) = 1 + \cos^2\theta$ (14.8)

$f_2(\theta) = 6.94\ (1.3 - \cos^2\theta)$

θ = conveyor angle as measured from the horizontal, degrees

$0.414 > \mu_1 > 0.374$

$0.554 > \mu_2 > 0.466$

14.1.3 Screw conveyor performance

The performance of a screw conveyor, as characterized by its capacity, volumetric efficiency, and power requirements, is affected by the conveyor geometry and size, the properties of the material being conveyed, and the conveyor operating parameters such as the screw speed and the angle of inclination. The effect of these factors is discussed below.

14.1.3.1 Capacity

Screw length has no effect on the capacity of a screw conveyor. The effect of speed and inclination is given in Figure 14.2. As shown in the figure, there is a limiting value of speed beyond which the capacity does not increase. In fact, it may even decrease beyond a certain speed. It is also seen from this figure that the capacity decreases as the angle of inclination increases. The limiting value of speed is independent of the angle of inclination. It has been suggested that there may be two factors responsible for this behavior: (1) the maximum possible rate of grain flow through an orifice, and (2) the centrifugal force due to the rotation of the grain mass. Initially, the capacity increases directly with speed up to 250 rev/min. After this point the centrifugal force restricts the flow of grain at the intake and causes the slope to decrease. If the speed is increased sufficiently the centrifugal force may become so restrictive as to cause a decline in the capacity.

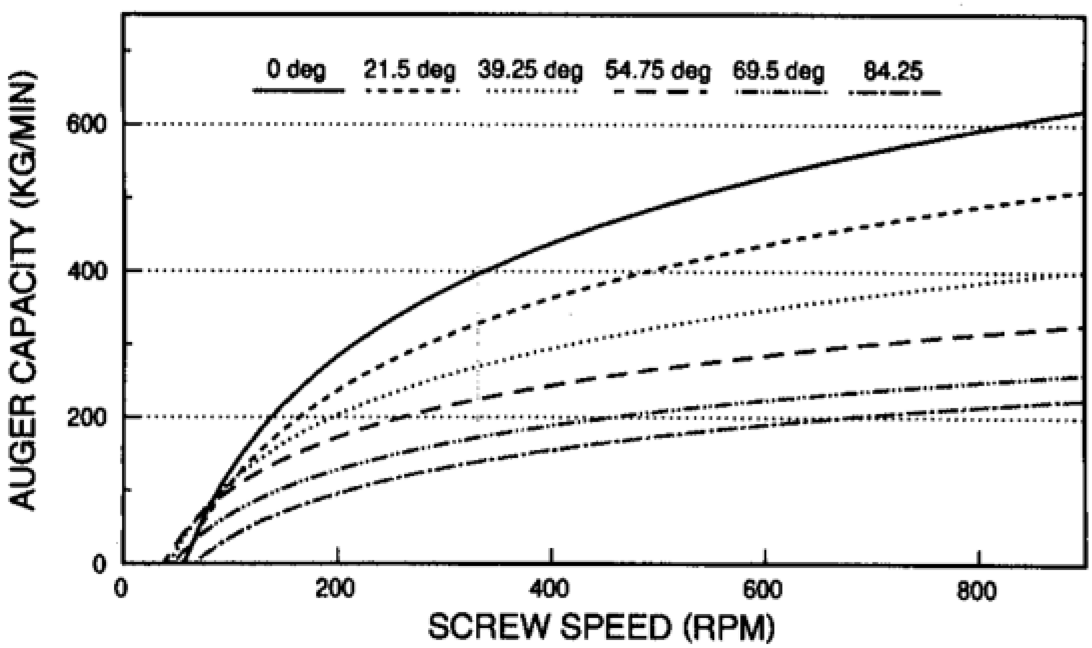


Figure 14.2 - Effect of screw speed and angle of auger inclination on conveying capacity (redrawn from Regan and Henderson, 1959).

Figure 14.3 shows the effect of screw angle of inclination on the capacity. The reduction in the capacity approximately follows the cosine function with two exceptions: (1) the capacity at higher speed is well below the cosine function, and (2) the capacity at 90 degrees angle is about 30% of the horizontal capacity. This may be due to the restriction to grain flow into the intake of the conveyor at higher speeds and the fact that grain flows from a vertical orifice at one-third the rate from a comparable horizontal orifice.

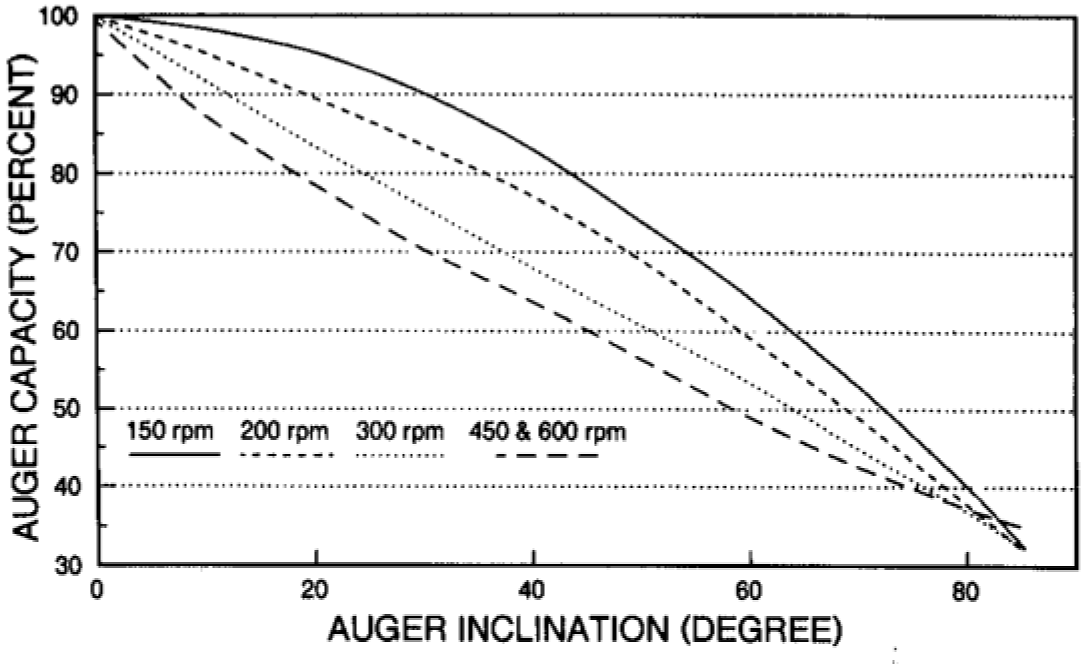


Figure 14.3 - Reduction in the auger conveying capacity as affected by the angle of inclination at different speeds (redrawn from Regan and Henderson, 1959).

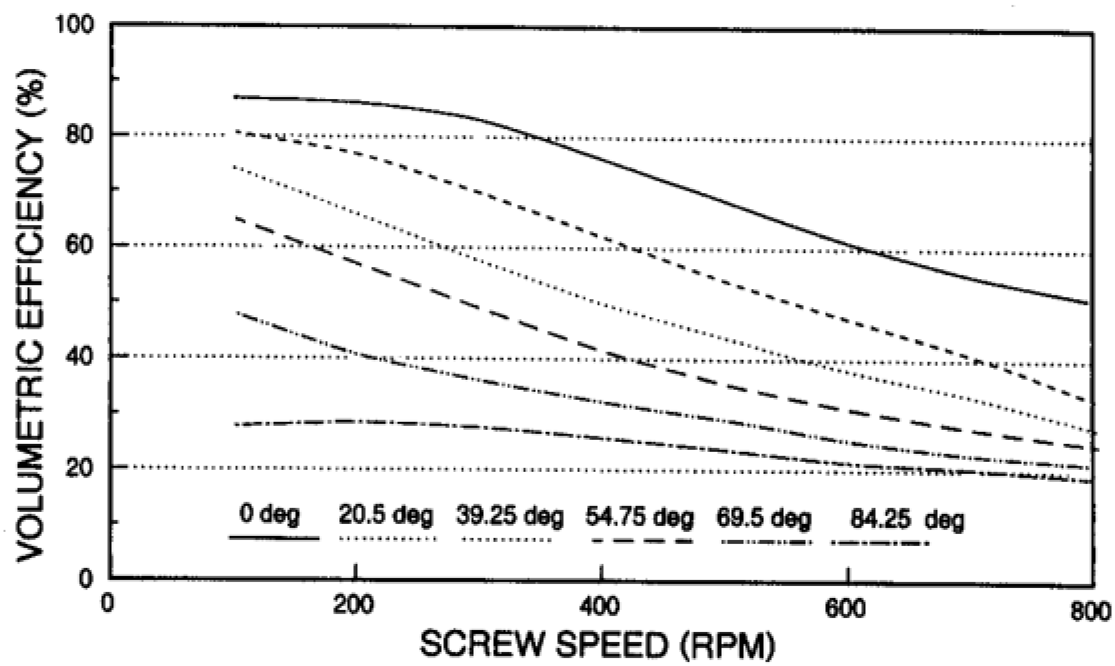


Figure 14.4 - Effect of screw speed on volumetric capacity at various angles of inclination (redrawn from Regan and Henderson, 1959).

14.1.3.2 Volumetric efficiency

Screw length has no effect on the capacity and volumetric efficiency of a screw conveyor. The effect of screw speed and inclination on volumetric efficiency is given in Figure 14.4. Generally, volumetric efficiency decreases as the screw speed and the angle of inclination increase. Brusewitz and Persson (1969) reported that the screw clearance affects the volumetric efficiency. As shown in Figure 14.5, the diametral clearances up to 5% to 7% have little affect on the volumetric efficiency, but a drop in efficiency of 0.7% per 1% increase in clearance can be expected. No interaction of the conveyor inclination and screw clearance is evident.

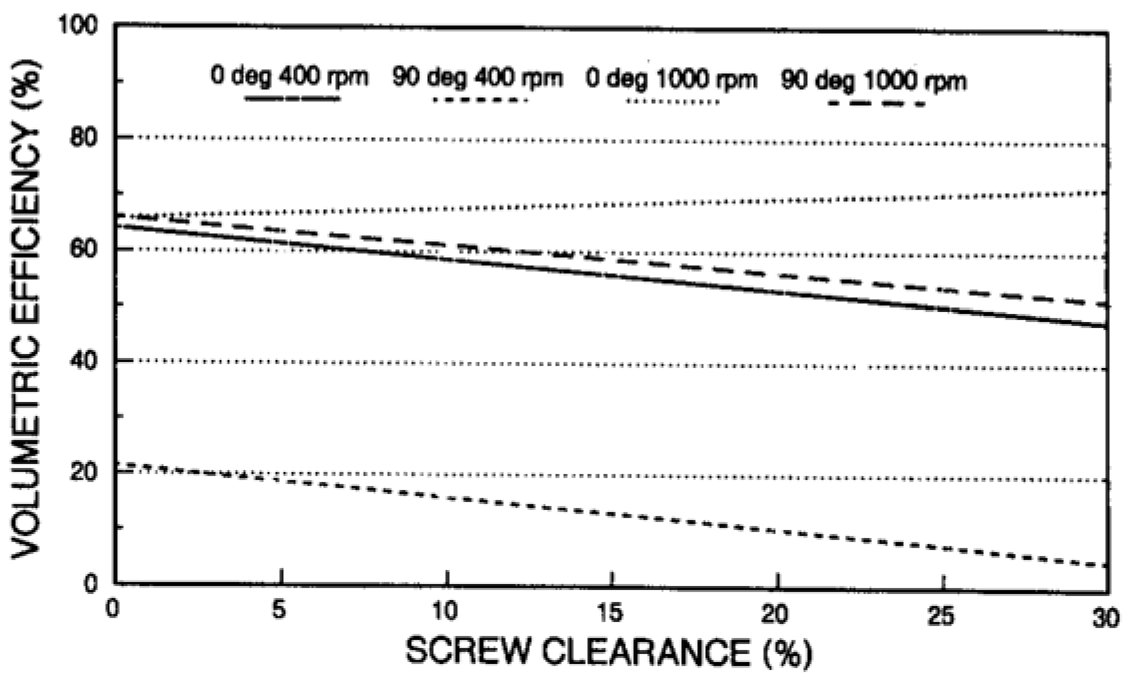


Figure 14.5 - Effect of the clearance between screw flightings and the tube inside diameter on the volumetric conveying efficiency (redrawn from Brusewitz and Persson, 1969).

14.1.3.3 Power requirements

The effect of screw diameter on specific power, as defined earlier, is dependent on the speed of a screw conveyor. At low speeds there is a decrease in the specific power with increase in the screw diameter. The trend reverses with higher speeds. Screw length has no effect on specific power. There is a slight effect of the pitch on the specific power. An increase in pitch tends to reduce the specific power. For horizontal augers, an increase in the diametral clearance causes a slight decline in the specific power. However, for vertical augers, this results in a general increase in the power. An increase in screw speed results in an increase in the required power as shown in Figure 14.6. The hump in the power curve below 300 rev/min is due to the high torque value at lower speeds. Increasing the angle of inclination causes the power to increase initially but a decrease follows beyond a certain angle. This is due to the decline in the volumetric efficiency. Moisture content that is associated with increase in friction causes the specific power to increase significantly.

Presently, concise data are not available for individual design problems. The selection is based on data provided by the manufacturers. Most data provided by the manufacturers are for low-speed horizontal augers. However, the equations given above may be used for estimating auger capacity and power requirements for a given application.

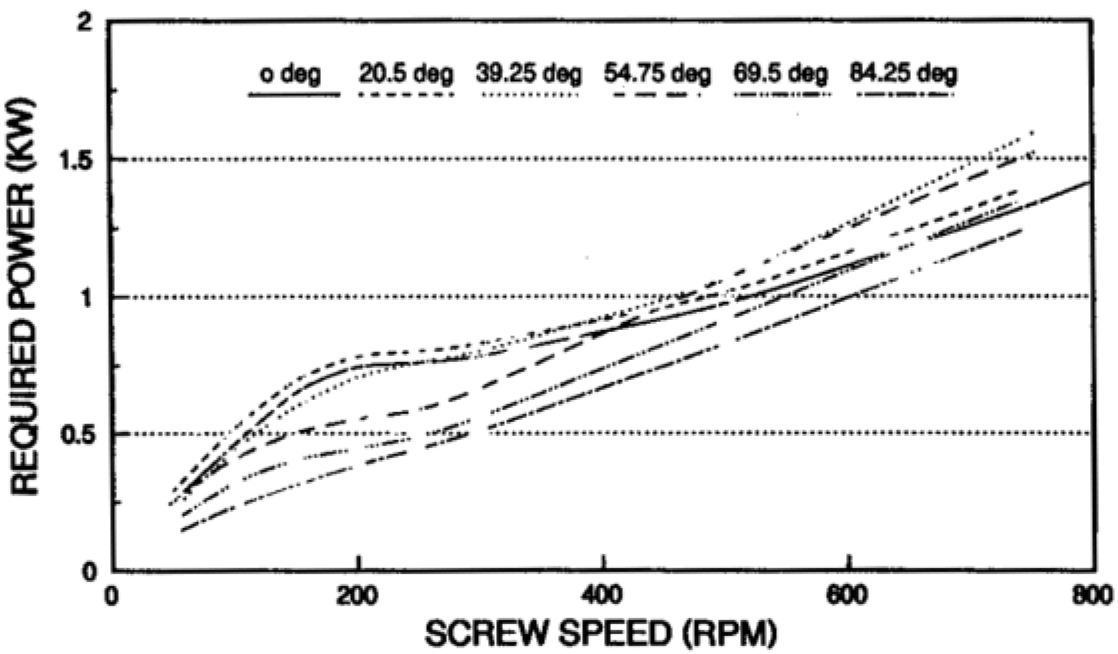


Figure 14.6 - Auger conveyor power requirements at different screw speeds and angles of inclination (redrawn from Regan and Henderson, 1959).

Example 14.1

Determine the efficiency, volumetric capacity, and power requirement of a horizontal standard pitch screw auger conveying wheat. The screw diameter is 15.24 cm (6 in.) and the shaft diameter is 2.54 cm (1 in.). The screw speed is 600 rev/min. The grain-metal friction may be taken as 0.414 while a value of 0.466 may be used for internal friction coefficient. The intake length of the screw is two times the pitch.

Solution

Given:	d_{sf} = 0.1524 m (6 in.)	μ_1 = 0.414
	d_{ss} = 0.0254 m (1 in.)	μ_2 = 0.466
	l_p = 0.1524 m (6 in.)	n = 10 rev/s (600 rev/min)
	l_i = 0.3048 m (12 in.)	θ = 0
	ρ_b = 769 kg/m^3 (Table 14.2)	

Table 14.2. Grain properties related to pneumatic conveying (ASAE Data D241.2).

Material	Bulk density, kg/m^3	Particle density, kg/m^3	Equivalent particle diameter, mm
Wheat	769	1300	4.08
Oats	410	1050	4.19
Barley	615	1330	4.05
Soybeans	769	1180	6.74
Corn	718	1390	7.26

Use Equation 14.6 to determine the efficiency. The dimensionless groups are calculated as follows:

$$2\pi n\sqrt{\frac{l_p}{g}} = 2\pi(10)\sqrt{\frac{0.1524}{9.81}} = 7.83$$

$$\frac{d_{sf}}{l_p} = \frac{0.1524}{0.1524} = 1$$

$f_1(\theta) = 2$

$$\frac{l_i}{l_p} = \frac{0.3048}{0.1524} = 2$$

Substituting in Equation 14.6 we get:

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\, l_p n} = (4.32\times 10^{-4})(7.83)^{-0.44}(2)^{0.31}(2)^{1.35}(0.414)^{-4.59}(0.466)^{-3.72}$$

$= (4.32 \times 10^{-4})(0.404)(1.24)(2.55)(57.3)(17.12)$

$= 0.541$

$\eta_v = 0.541$ or 54.1%

Volumetric capacity can be found as:

$$Q_a = 0.541\frac{\pi}{4}\left[(0.1524)^2 - (0.0254)^2\right](0.1524)(10) = 0.0146\,m^3/s\,(\text{or } 40.5\,t/h)$$

Use Equation 14.7 to determine the power requirement.

$$\frac{P/L}{Q_a \rho_b g} = 3.54(7.83)^{0.14}(1)^{-1012}(2)^{0.11}(2.082)(0.466)^{2.05}$$

$= 3.54(1.334)(1)(1.079)(2.082)(0.209) = 2.217$

$P/L = 2.217(0.0146)(769)(9.81) = 245$ W/m

Appendix J: Resumes

Résumés of Team Members

The following pages present two-page résumés of the team members for this project.

Colt Medley

2139 E. 100th St. N. Wagoner, OK 74467
(918)-645-0038
colt.medley@okstate.edu

Objective

- Seeking a full time position in an Engineering or Petroleum Exploration and Production field.

Skills

I can create advanced 3-D components and assemblies in Solid Works and have a good understanding of Finite Element Analysis. I also am proficient in Cad Key.

Proficient in Microsoft Word, Excel, Vba, and PowerPoint

Education

- **3.67 Technical GPA**
- Bachelors of Science Degree in Biosystems Engineering- Mechanical Option
- Minor in Petroleum Engineering
- Graduation from Oklahoma State University Date- May 2013

Relevant Experience

Engineering Intern **Ren Corporation** **Fall 2012-Present**

Assisted engineers and worked with a team of professionals who assemble million dollar hydraulic testing machines for companies all over the world. There I work with Cad Key and Solid Works assisting in the production of schematics for the machines.

Assistant Forman **Parents House** **Summer 2012**

Assisted in the construction of my parents' house. We started from an empty steel building I fabricated all the corrals, corner posts, and an archway, framed bedrooms, doorways and windows. I wired our home, plumbed the barn, operated heavy machinery for the formation of roads, sheet rocked the garage, laid hard wood floor in the whole house.

Assistant Wrangler **Lone Tree Bible Ranch** **Summer 2006 to 2009**

At Lone Tree Ministries we used the outdoors and adventure based activities to share Christ with each camper in a gentle, natural way through personal attention and relationships built through the activities. During the duration of two months in the summer, I took care of the horses which consisted of grooming, feeding, training, assisting other wranglers on the trail rides, and overnighters out and camp in the open prairie where we contribute to the personal relationships of campers with Jesus Christ. www.lonetreebibleranch.com

Horse Trainer & Farm Hand **Family Farm** **1997-Present**

Trainer at Shining M shooters ranch of many world class shooting, team roping, and reining horses from a vast number of clientele, over thirteen years of experience. Operating and repairing necessary machinery such as tractors, power tools, implements, etc. Perform chores, build fence and maintain structures.

Honors and Activities

American Association of Directional Drillers
Several Honor Roll certifications
Honors Scholarship for Academics Tulsa Community College (2008-2010)

References Available Upon Request

Tim Hunt
221 S. Washington St. Apt 2 ♦ Stillwater, OK 74074 ♦ 913-375-3623 ♦ tim.hunt@okstate.edu

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OBJECTIVE: Seeking an internship to gain experience in designing and developing sustainable energy and agricultural resources.

SUMMARY: A Biosystems and Agricultural Engineering student with an emphasis in Biomechanical design. I have taken courses that cover topics such as machinery processing, mechanical power, microbial technologies, and instrument circuitry. I have experience using design software such as Pro-Engineering and Solid Works.

Education

Oklahoma State University, Stillwater, OK — Aug 09-Dec 13

Bachelor of Sciences in Biosystems and Agriculture Engineering (Biomechanical emphasis)
Spanish Minor
Cumulative GPA: 2.7/4.0

Qualifying Skills

Pro-Engineer Software
Solid Works Software
Arduino Programming
Basic Stamp II Programming
Visual Basic for Applications
Microsoft Office Applications
Residential Construction
Small Engine Repair and Maintenance

Clubs and Organizations

American Society of Agriculture and Biological Engineers (ASABE)
Cowboy Motorsports (1/4 Scale Tractor Competition)
International Social Fraternity

Leadership Experience

ASABE Student Branch — *Spring '12-Present*
Oklahoma State University, Stillwater, OK
CASNR Representative

Involvement in International Social Fraternity — *Fall '09-Present*
Oklahoma State University, Stillwater, OK
Member Recruitment Chair
Sergeant at Arms
Scholarship Board

Professional Experience

Eskimo Joes, *Bartender,* Stillwater, OK *May 11-Present*

Utilize communication skills with managers, co-workers, and customers.

Practice prompt service and response time to satisfy guests.

Schlitterbahn Vacation Village, *Lifeguard,* Kansas City, KS *May 10-Aug. 10*

Earned lifeguard certification.

Participated in weekly customer service protocol seminars.

Seal of Approval Landscaping, *Laborer,* Kansas City, KS *May 05 – August 09*

Renovate houses, landscaping labor, snow removal.

Practice small engine repair and maintenance.

Tarron Ballard

9216 S. Rose Rd. | tarron.ballard@okstate.edu
Perkins, OK 74059 | Tarron Ballard | (918)-509-0547

Objective:

To obtain a career as an Engineer in the oil and natural gas industry

Skills and Accomplishments:

Engineering Internship with Weatherford International
Study Abroad Class: Technologies of Brazil
Senior Design Project with Halliburton

Education:

Bachelor of Science in Biosystems Engineering May 2013
Minor in Petroleum Engineering
Oklahoma State University
GPA: 3.11/4.00

Professional Experience:

Engineering Internship May 2012-July 2012
Weatherford International, Completions Department
Took completion courses and packers practical rig applications class
Helped rebuild packers in the shop
Went to locations with tool hands and helped run plug and packer jobs

Cashier, Parts Specialist 2011-Present
Napa Auto Parts-Main Auto Supply
Responsible for helping customers find what they need and making sells
Make deliveries to customers
Keep shelves stocked and up to date

Carpet Cleaner 2009-2011
Short's Carpet Cleaning
Responsible for driving the van and cleaning machine to the customer's home
Discussed job requirements with customer and gave customer quote for the job
Cleaned the carpet to the customer's satisfaction
Responsible for collecting payment and carrying up to $500

Maintenance Worker May 2009-July 2009
Cimarron Trails Golf Course
Responsible for taking care of the club house lawn

Installed sprinkler systems
Mowed and any miscellaneous work needed

Day Manager August 2008-May 2009
Edge Tanning Salon
Responsible for opening and closing
Sold tanning packages and tanning products
Responsible for closing daily transactions and dropping of deposits at the bank

Assistant Cabinet Maker May 2008-August 2008
DJ Cabinets
Responsible for painting, staining and lacquering cabinets
Built drawers, doors, shelves and assisted in building cabinets
Responsible for delivering and installing the cabinets

Activities:
Study Abroad Class: Technology of Brazil
Volunteer at LifeChurch.tv Stillwater

Honors:
Dean's Academic Excellence Scholarship 2011 and 2012
Academic Excellence Scholarship
Blair and Mary Stone Scholarship
Honors Classes:
Engineering Computer Programming
American Government

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OPTIMIZING AUGER OUTPUT

BADco.

A contract engineering firm associated with:

HALLIBURTON

Colt Medley
Tarron Ballard
Tim Hunt

MEET THE TEAM

Colt Medley

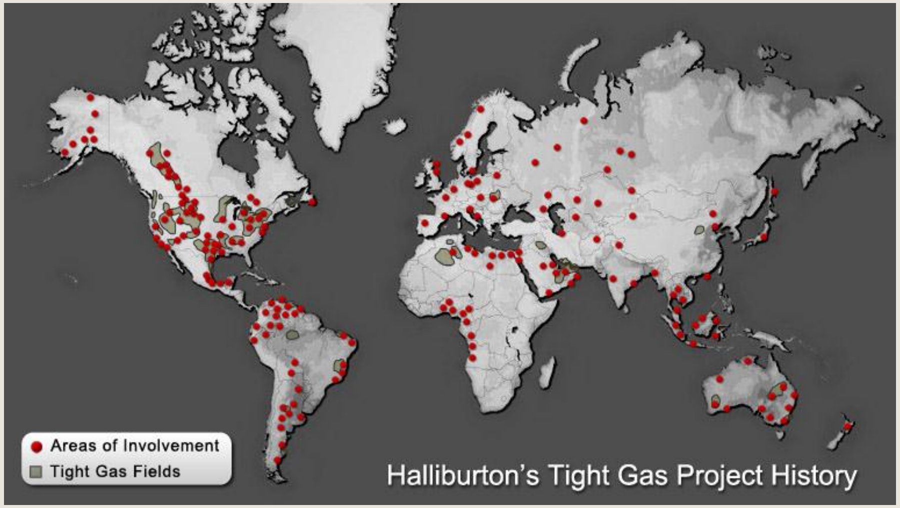
Tarron Ballard

Tim Hunt

PROJECT BACKGROUND

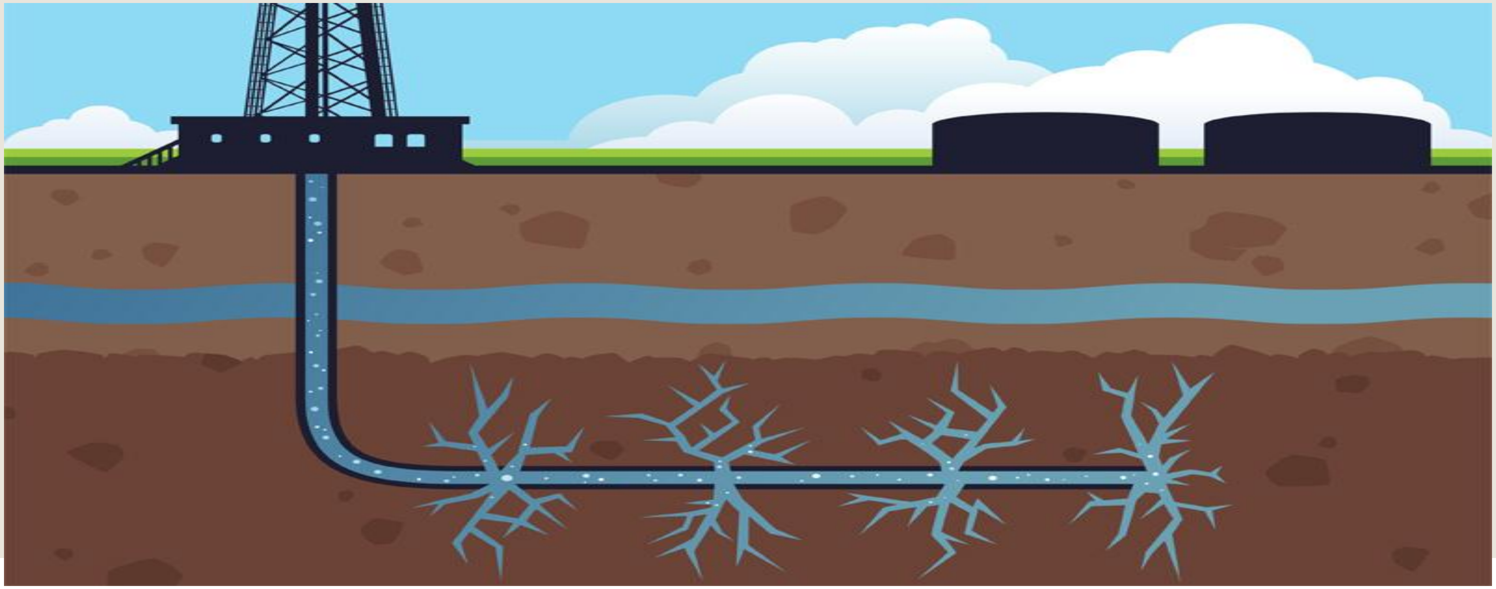
COMPANY BACKGROUND

- Founded in 1919 by Erle P. Halliburton in Duncan, OK.
- Employs over 70,000 workers in about 80 countries.
- Supports upstream oil and gas industry in many ways
  - Managing geological data
  - Drilling and formation evaluation
  - Well construction and completion
  - Optimizing production throughout the life of the well



HYDRAULIC FRACTURING

- Process first used in 1947 on Hugoton natural gas field in Kansas.
- Water and sand are forced into a rock formation to create tiny fractures that allow gas or oil to escape.
- Process takes 3 to 10 days to complete.
- Around 19,000 wells were fracked last year.



Halliburton Fracturing Job Site

FB4K BLENDER

- Each unit costs $1M to produce.
- Each screw conveyor costs around $20K.
- Proppant costs $1.50 to $7.00 per pound.
- Each job takes from 250,000 to 1,000,000 pounds of proppant.
- Average lifetime of each screw is 15 years.
- FB4K Blender:

PROJECT OUTLINE

- **Project Proposal Details:**
  - Screw conveyors are used to meter proppant into the mixing tub on the FB4K.
  - Over a certain speed, the output is not linear.
  - We will optimize the design to increase the linear output operating range.

OBJECTIVES

- To improve the accuracy and output of the FB4K Blender's sand screws by:
  1. Deriving an equation that describes output.
  2. Propose designs to improve overall output.
  3. Build and test prototype of the accepted designs.
  4. Derive an equation that describes the newly designed auger's output.

DEVELOPMENT OF DESIGN CONCEPTS

CONTROL DESIGN

- One 6” diameter, 11’ long auger, 4”-6” pitch
- Standard bin
- Operates at a 45 degree angle

LARGER BIN

- Not completely filling up bin
- Proppant doesn't have time to surround screw completely at high RPM
- Increased volume from 244 in^3 to 382 in^3

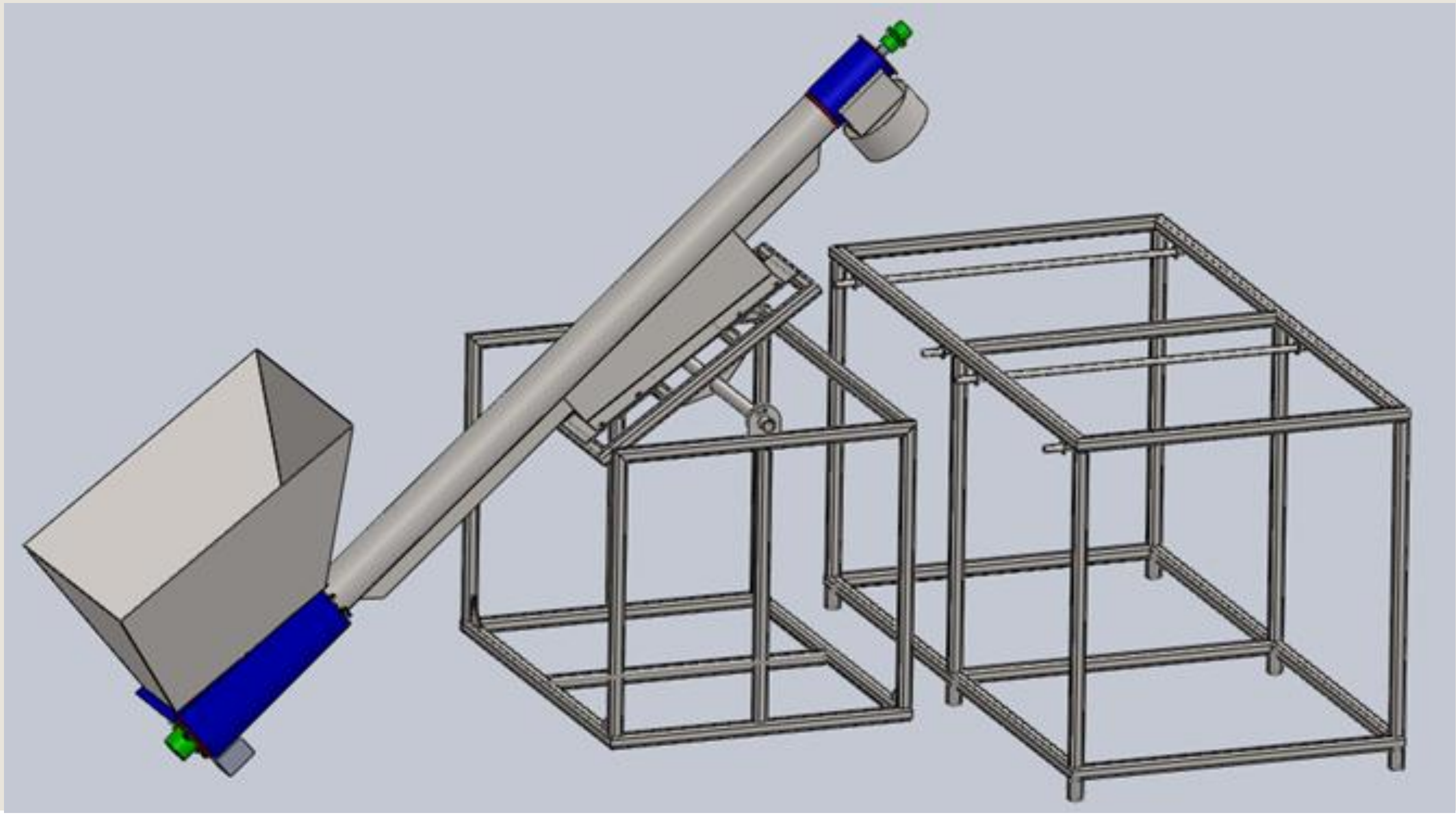
REMOVAL OF TUBE EXTENSION

- Vertical angle may allow gravity to pull proppant away from tube
- Auger housing extends into the hopper, limiting availability of proppant

PROTOTYPE TESTING

PROTOTYPE

- We received an old conveyor from Halliburton to use for testing. The hopper, conveyor stand, and sack stand were fabricated in the BAE Lab.



TEST SETUP

TEST RUN

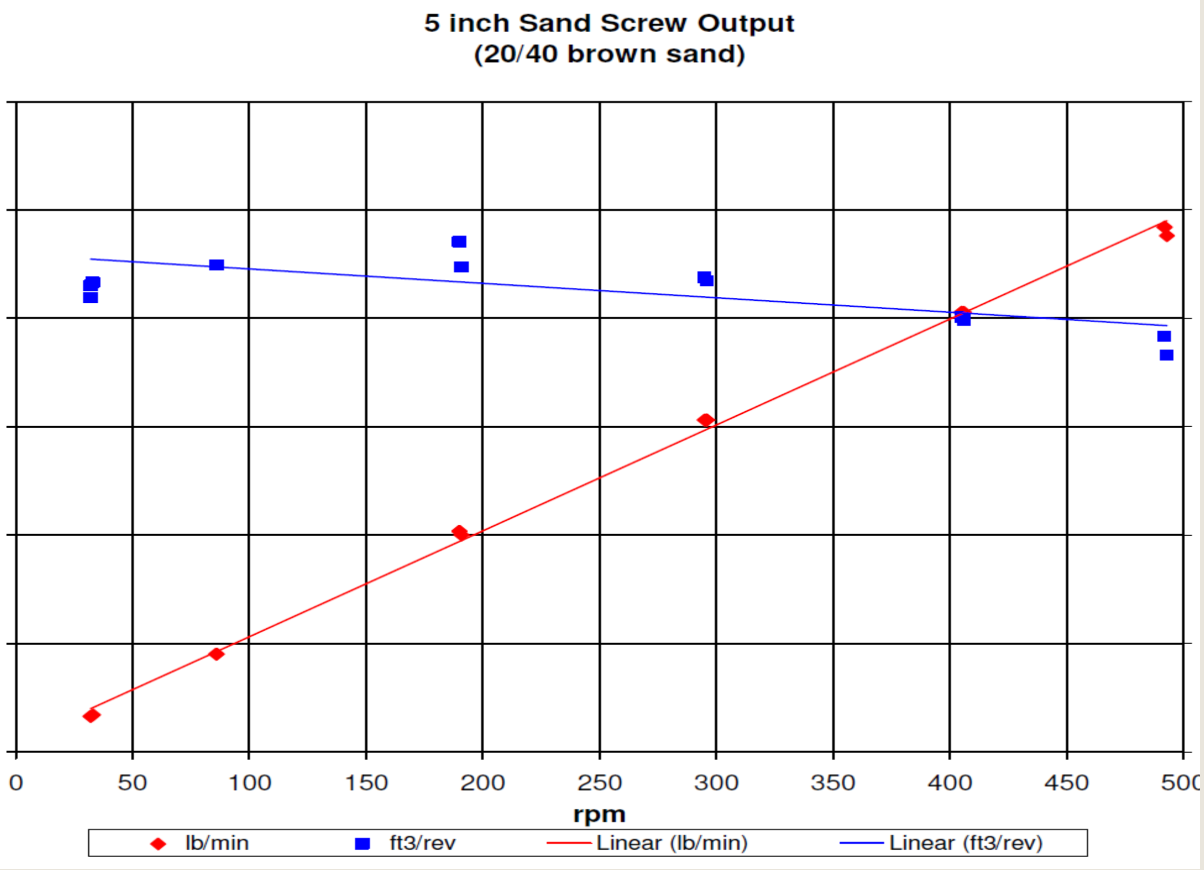
TEST RESULTS

DATA COLLECTION

- Test data was taken from each design at intervals of 100 RPMs from 200 to 700 RPMS.
- Each speed was tested three times.

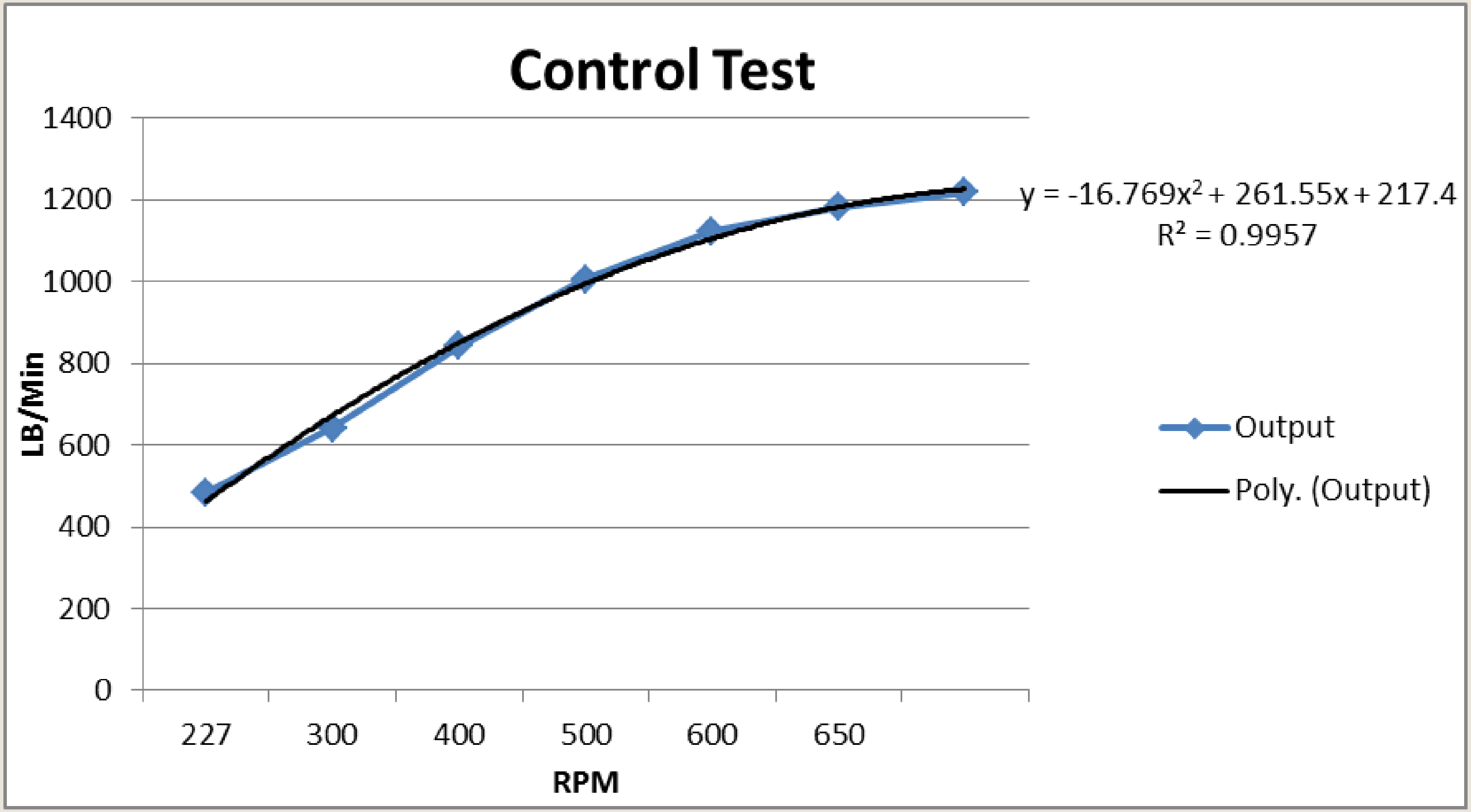
CURRENT DESIGN

- One 6” diameter, 11’ long auger, 4”-6” pitch
- Halliburton test data:



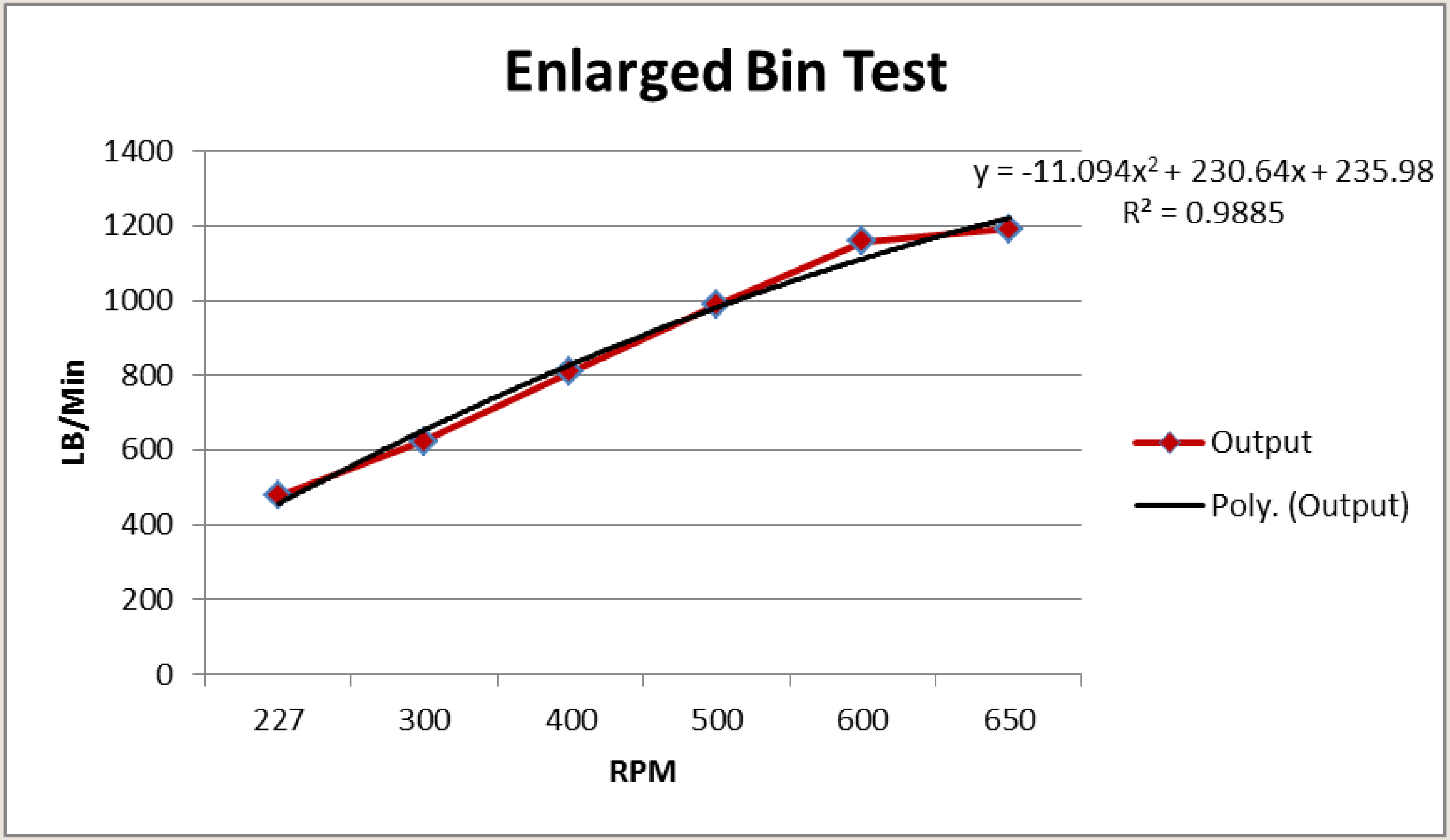
RESULTS

Control test showed a decline in output at 600 RPM



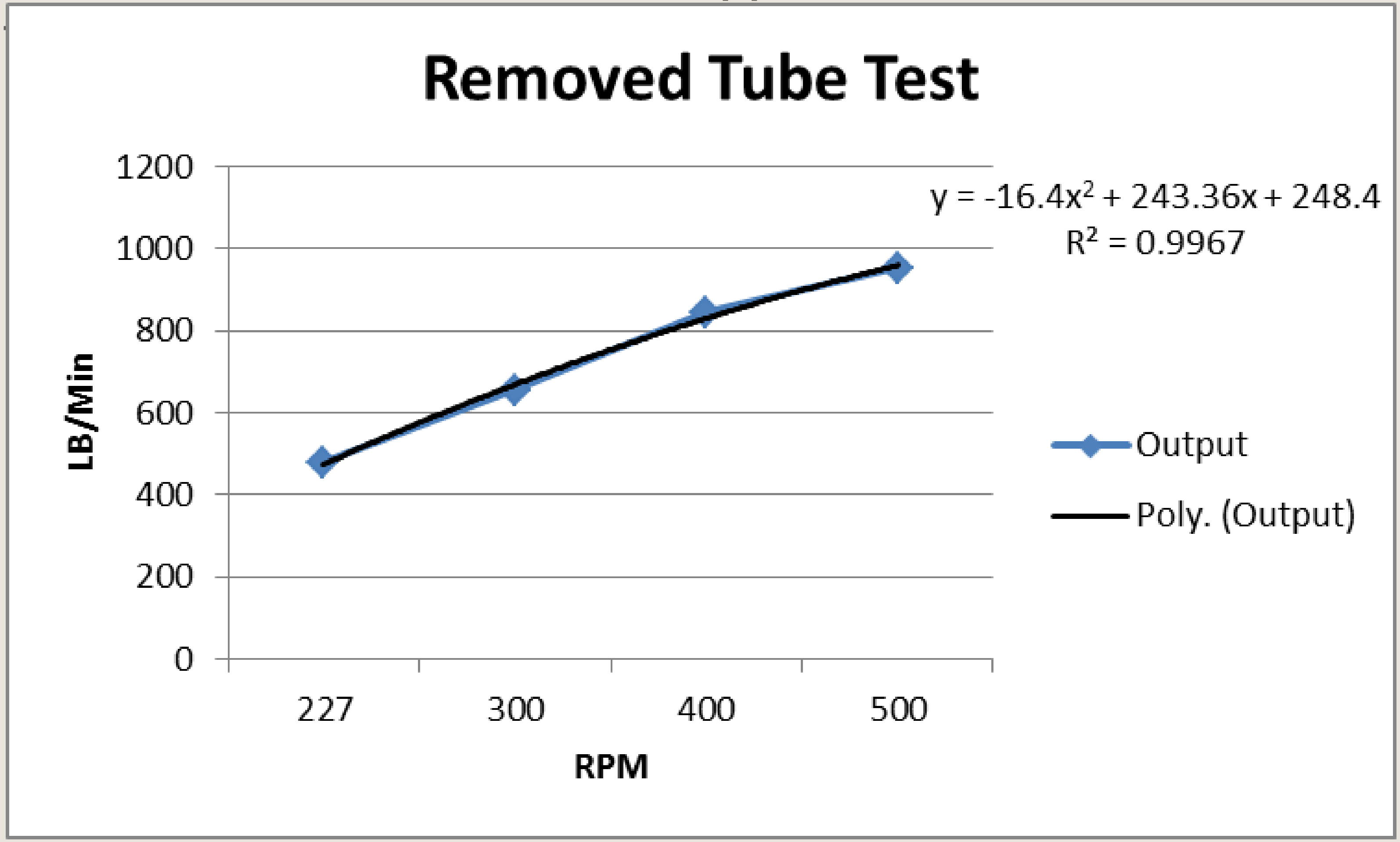
RESULTS

- The larger bin showed data similar to the control test



RESULTS

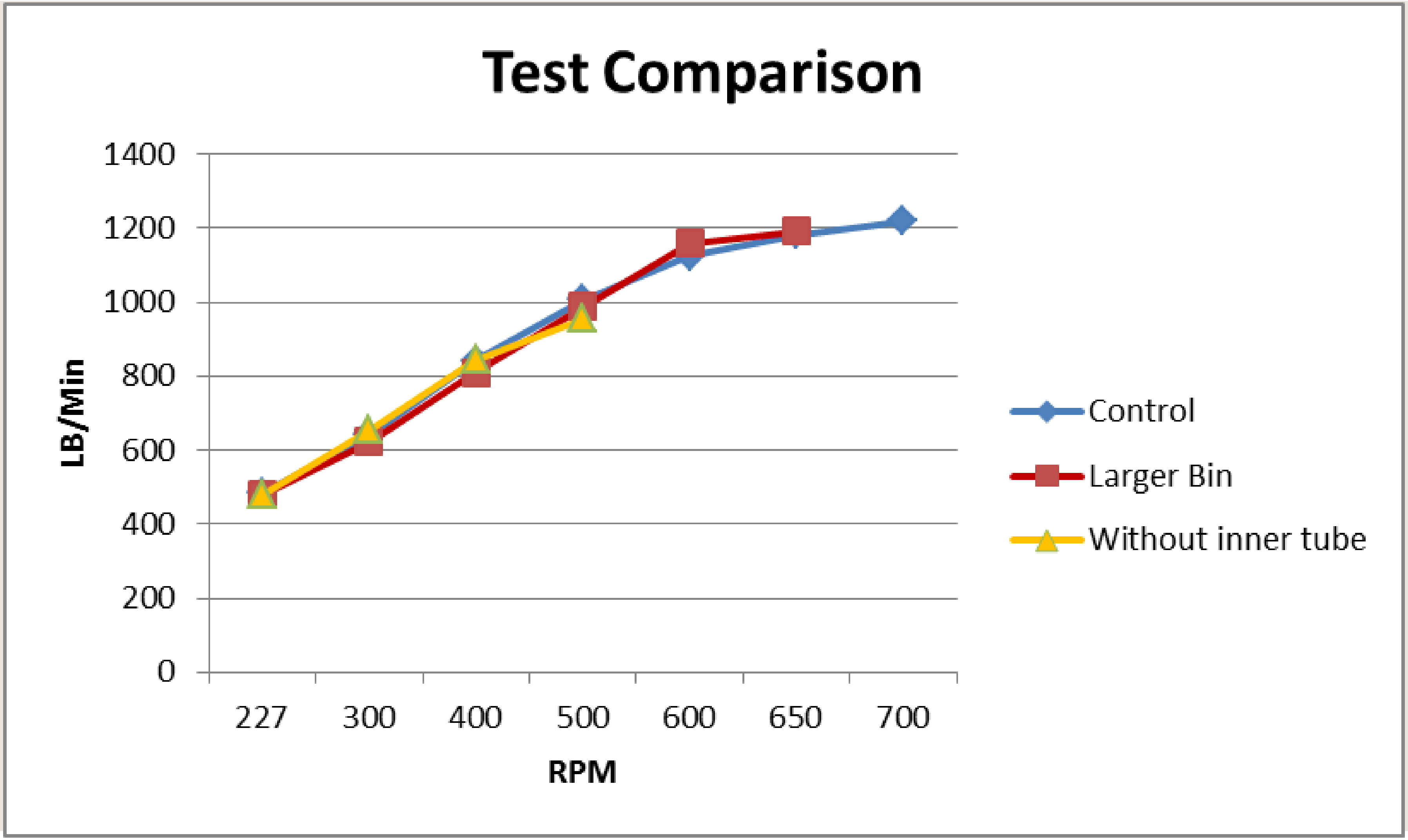
- Test without the tube in the hopper were similar to the control



TESTING FAILURE

Supersack ripped during final tests and tipped over the auger.

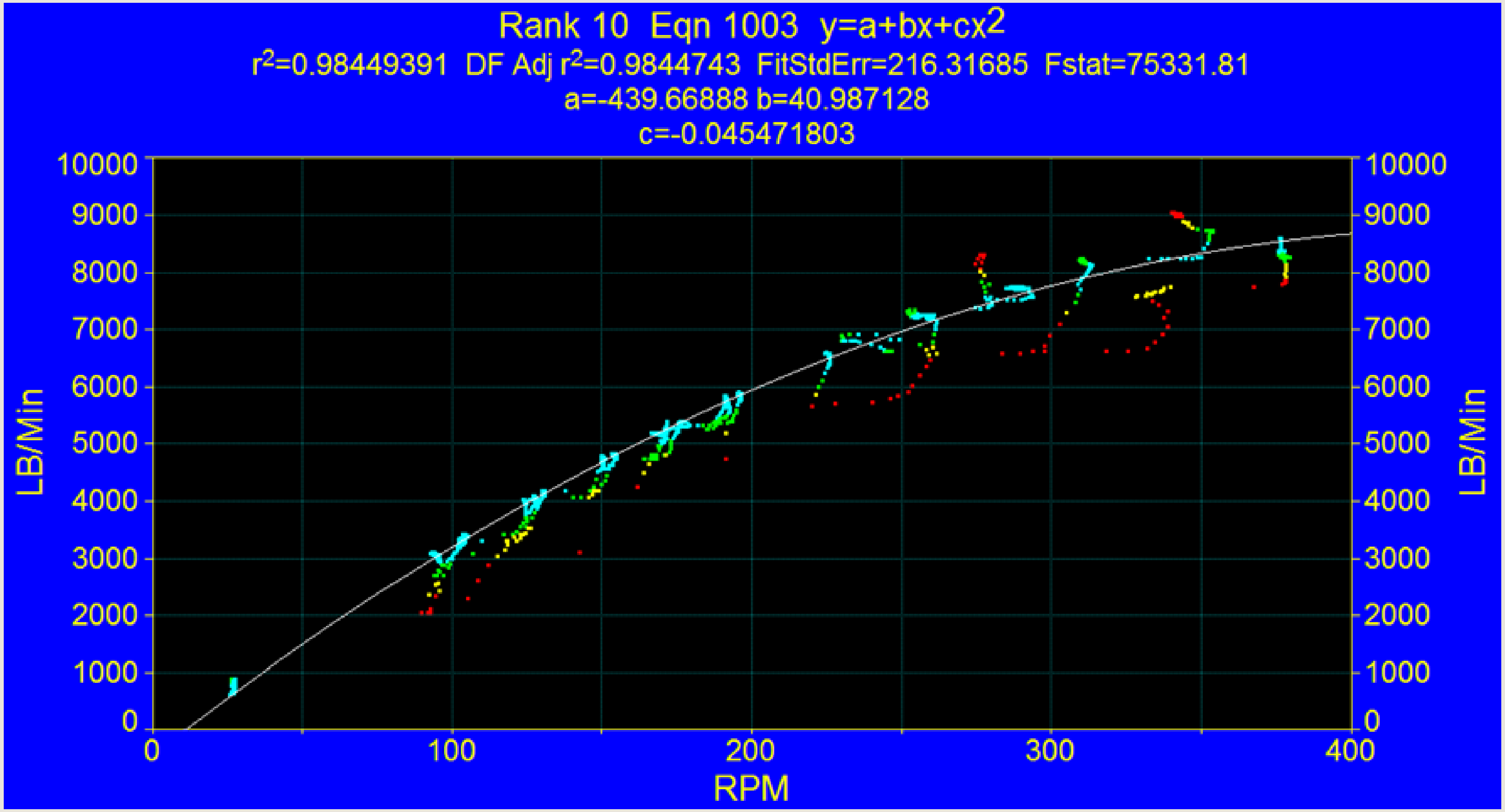
RESULTS



Test Comparison
1400
1200
1000
800
600
400
200
0
LB/Min
227
300
400
500
600
650
700
RPM
Control
Larger Bin
Without inner tube

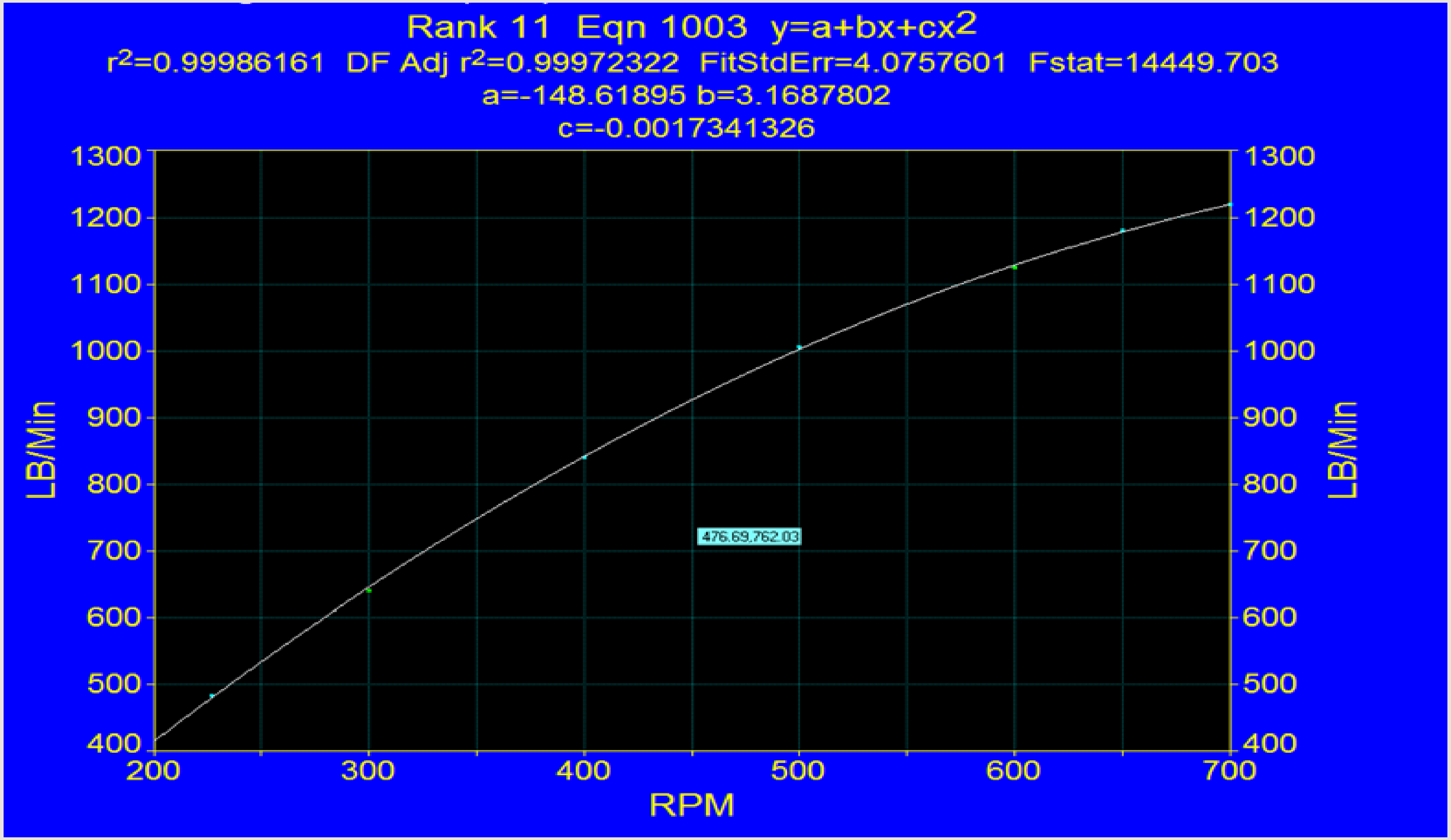
TABLECURVE

- Data from Halliburton's 12" auger testing
- Slope stays positive, but keeps decreasing at high RPMs.



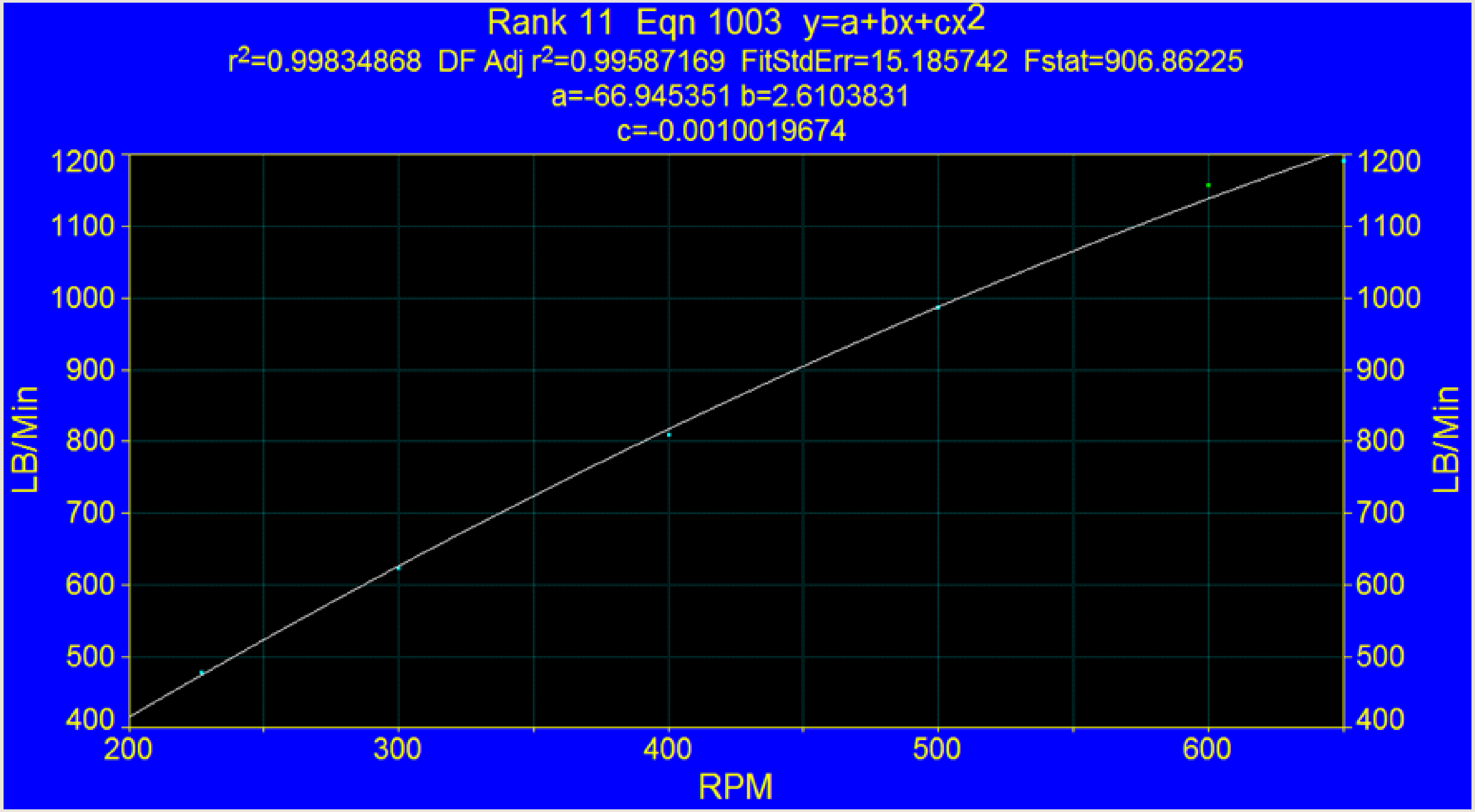
TABLECURVE

- Control test data: $y=-148.6+3.17x-0.0017x^2$



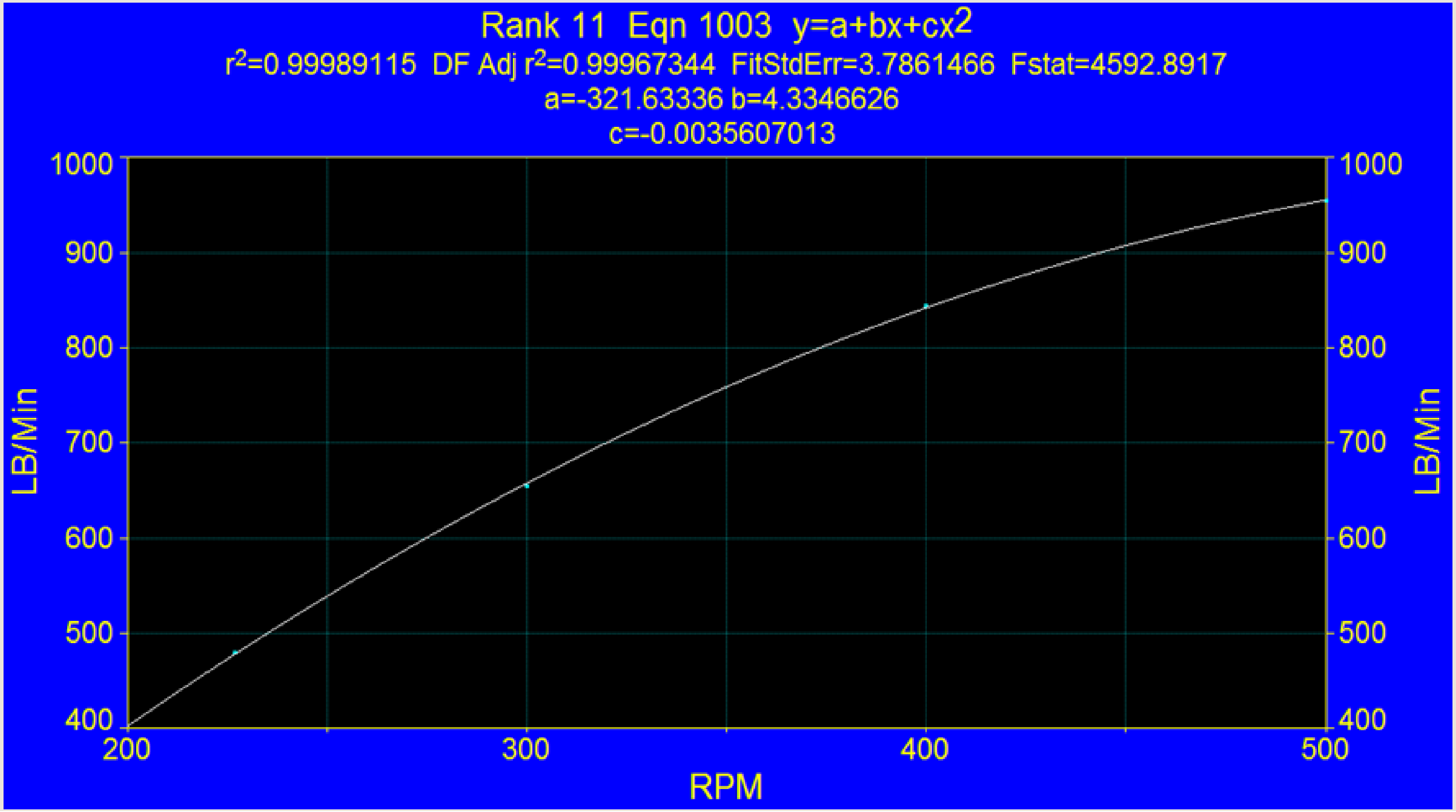
TABLECURVE

- Enlarged bin data: y=-66.95+2.61-0.001x²



TABLECURVE

- Removed Tube data: $y=-321.63+4.33x-0.0036x^2$



CONCLUDING REMARKS

BUDGET

- Halliburton offered us a budget of $5000-$10,000.
- Estimated costs were $3000.
- Actual budget covered all expenses besides auger and sand sent from Halliburton:

Payee	Payment
McMaster-Carr	$686.73
Stillwater Steel & Welding	$660.60
Napa Auto Parts	$380.87
BEI Sensors	$507.00
Brewer Carpet One	$79.20
Total:	$2,314.40

SCHEDULE

Task Name	Duration	Start	Finish
Optimize Auger Output	**185 days**	**Mon 8/27/12**	**Fri 5/10/13**
Produce Equation	**55 days**	**Mon 9/3/12**	**Fri 11/16/12**
Get test data from Halliburton	5 days	Mon 9/3/12	Fri 9/7/12
Analyze data in excel	10 days	Fri 9/7/12	Thu 9/20/12
Analyze data in TableCurve	14 days	Fri 9/21/12	Wed 10/10/12
Evaluate TableCurve equations	27 days	Thu 10/11/12	Fri 11/16/12
Choose best equation	1 day	Fri 11/16/12	Fri 11/16/12
Redesign equipment	**51 days**	**Mon 9/24/12**	**Sat 12/1/12**
Make SolidWorks drawing of 6" auger	15 days	Mon 9/24/12	Fri 10/12/12
Analyze current design shaft stresses	28 days	Mon 9/24/12	Wed 10/31/12
Generate redesign options	32 days	Fri 10/12/12	Mon 11/26/12
Choose best design options for prototypes	32 days	Fri 10/12/12	Mon 11/26/12
Prototype Testing	**85 days**	**Mon 1/7/13**	**Fri 5/3/13**
Acquire Equipment	**41 days**	**Mon 1/14/13**	**Mon 3/11/13**
Assemble Bill of Materials	12 days	Fri 1/11/13	Sat 1/26/13
Get Halliburton Auger	3 days	Tue 2/5/13	Thu 2/7/13
order auger flighting	7 days	Thu 2/28/13	Fri 3/8/13
make sheet metal bin hoppers	11 days	Mon 2/25/13	Mon 3/11/13
proppant	19 days	Thu 2/7/13	Tue 3/5/13
Test stand	40 days	Mon 1/14/13	Fri 3/8/13
test site	19 days	Mon 1/14/13	Thu 2/7/13
Testing	**23 days**	**Wed 3/13/13**	**Fri 4/12/13**
Set up equipment	6 days	Fri 3/8/13	Fri 3/15/13
run control test	11 days	Fri 3/15/13	Fri 3/29/13
change variables	11 days	Fri 3/29/13	Fri 4/12/13
Results	**67 days**	**Thu 1/31/13**	**Fri 5/3/13**
analyze test results	7 days	Sat 4/13/13	Sat 4/20/13
produce equation that describes new prototype output	7 days	Sat 4/13/13	Sat 4/20/13
compare prototype equation with current design equation	3 days	Sat 4/20/13	Tue 4/23/13

CONCLUSION

- Our deliverables have been achieved for both semesters.
- Data was collected outside of the linear range for multiple design prototypes.
- We recommend that Halliburton explore changed in flighting.
  - A concave flighting design or a lip on the edge of the flighting might account for the centrifugal force on the sand.

ACKNOWLEDGEMENTS

We would like to especially thank the following people for their contributions to our effort:

Paul Weckler

Carol Jones

Wayne Kiner

Jason Walker

Aaron Franzien

Chad Fisher

Wesley Warren

Randy Taylor

Sarah Powers

Jana Moore

Jannice Hicks

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QUESTIONS?

BADco.

Proposal for the Redesign of the Halliburton FB4K Blender Auger System

Presented by Biosystem and Agriculture Design Company:
Colt Medley
Tarron Ballard
Tim Hunt
Biosystems and Agricultural Engineering, Oklahoma State University

Submitted to—
Chad Fisher (Frac Blending Systems) Halliburton
Dr. Carol Jones P.E.
Biosystems and Agricultural Engineering, Oklahoma State University

Contents

Executive Summary

Halliburton contacted Biosystem and Agriculture Design Company (BAD Co.) to develop a solution to an issue that they have experienced with the FB4K Blender. The FB4K Blender uses three sand screws, three dry feeders, and seven liquid additive systems to blend together a variety of proppants and liquids. The specifications of the mixture can be altered to accommodate the job at hand. The three sand screws, which move the proppant into the blender, are the source of the issue that we are faced with. The output experienced by the screws remains linearly proportional to the speed of the screw until it nears its peak RPM. Each screw experiences a decline in output when the operating speed reaches a certain point. We are faced with the task of accounting for this decline in output. To solve the problem, we will first develop an equation that describes the loss of production. This equation is able to be integrated with the FB4K's operating system to adjust the output of the liquid additive system as the output of the screws declines. Second, we will propose a new design for the sand screw that will allow a higher range of linear output. It is our goal to provide Halliburton with a solution that can be simply integrated with their current process.

Statement of Problem

Halliburton has given us permission to review their current designs and test data. We have been asked to improve the accuracy of the data and also the operating range of the design. This will be done by finding an equation that characterizes the auger output past its linear range of operation. Once the accuracy and operating range are satisfactory, we are asked to propose a new design for the sand screw system. This new design will be tested to see if the changes make any improvement. Our goal is to design an auger that shows less decline in output than the current design in production.

Identifying Customer Needs

"We would like for you to review at our design and test data and propose some changes you would make to improve accuracy and operating range. From there, we would like you to build prototypes of different size augers (does not have to something we could put into production) and test to see if the changes make any improvement. I think the prototypes should be 6" or smaller, otherwise the output will be very difficult to handle. We can provide some monetary assistance with this (would like to keep it between \$5-10k). We would also like you to look into an equation to characterize the auger output past its linear range of operation."

–Chad Fisher, Halliburton

Design Objectives

- Use current design data to derive an equation that describes auger output at all ranges.
- Propose design changes that will improve accuracy of auger output at high RPMs.
- Build a prototype of the design which offers the most probable solution to the problem.
- Test our prototype using different grades of commonly used proppants.
- Review and analyze prototype test data to determine the accuracy of new design.
- Derive an equation that describes the newly designed auger output at all ranges.
- Compare current design and prototype data.

Statement of Work

The purpose of our project is to determine why Halliburton's augers on the FB4K Blender have a declining output when operating at high RPMs. We will discover the source of the problem by first analyzing test data that has already been gathered by Halliburton. We will produce an equation that describes the output of the auger at varying RPMs. We will also design and test a prototype that may or may not be capable of being put in to production.
Using the provided output versus RPM data that has been provided, we will create a model that simulates the auger's production. This model will allow us to diagnose what part of the system we will alter to improve the output. We will redesign one or more parts of the auger and build a prototype. Running tests on this prototype will provide data that shows if our new design improves the output. We will then make an equation that describes the output of our new design.

In order to deliver equations and a prototype, we will need to:

- Analyze the test data provided to us.
- Enter the data into modeling software and carry out simulations.
- Analyze the simulation results to develop an equation describing the output.
- Generate design concepts to consider for implementation.
- Select the most effective design concept to propose.
- Design the proposed change using SOLID WORKS.
- Submit proposals to Halliburton for them to decide which one we should manufacture and test.
- Test prototype and use data to create a new equation that describes the output of the new design.

Period of Performance

By November 16th, we will have equations that represent the output of multiple sizes of augers at variable speeds. All of our design options were finalized by November 26th. On December 5th, we will present all of our design options and other solutions to Oklahoma State University staff and students, as well as Halliburton employees. We hope to have all our prototype parts delivered by January 31st. We visited Halliburon's facilities in Duncan, Oklahoma twice this semester, and hope to visit at least twice next semester as well.

Deliverables Schedule

Fall 2012

- Equation for the nonlinear curve from given data
- Multiple designs to correct nonlinearity
- Proposal to present findings and possible solutions

Spring 2013

- Prototype of finalized design
- Test data from prototype
- Equations that describe performance of prototypes
- Final report comparing new test data and equation to originals

Applicable Safety Standards

Augers do a lot of hard material handling work that would otherwise be done manually. Augers also can cause many injuries due to a lack of awareness of the possible dangers. Shield should be properly installed on our test auger to prevent materials from being thrown from the setup. Shields will also prevent users from becoming tangled in the equipment. Wearing close-fitting clothes when operating the auger will also help us to avoid becoming tangled in the auger. If our test auger has wheels on it, it will be very important to put blocks behing the wheels for stability. If the auger does not have wheels, the base must be stable enough to not tip over. Every test, the auger should be completely emptied to avoid issues when restarting the auger for the next test. As with all experiments, protective eyewear should be worn at all times when the equipment is running. Standard testing safety procedures (eye, ear, clothing protection). Stay clear of all operating equipment during testing. Our prototype will only be used for testing, and will not be put into production. Therefore will not need to consider industry safety standards, and only put safety precaustions in for ourselves.

Technical Specifications

We are presented with two different sizes of augers:

- The 6 inch auger produces up to 800 lb/min at 400 RPM.
- The 12 inch auger produces up to 9000 lb/min at 400 RPM.

Strengths of each auger:

- The drive for the auger is adequate for the current usage.
- 6 inch auger has linear output up to 200 RPM, where it sees an output of 500 lb/min.
- 12 inch auger has linear output up to 200 RPM, where it sees an output of 6000 lb/min.

Weaknesses of each auger:

- Above 400 RPM, the output rate starts to decline.
- The material feed rate may be too slow to entirely fill the auger.
- The pitch and flighting may not be optimized to be completely filled on every rotation of the screw.
- The angle of the hopper may not allow the proppant to properly fill the auger.
- The space between the auger and its housing tube may allow sand to fall between flights.
- Housing extending into hopper limits proppants availability to auger.

Possible Solutions:

- Use output detecting sensor to adjust mixing fluid input.
- Change flighting of the current augers (length, thickness, spacing, and angle of blade).
- Change angle of the whole auger.
- Integrate an equation into a control system that will calibrate automatically for the output decline.
- Change hopper design
- Make tighter tolerance between screw and housing.

Acceptance Criteria

Acceptable work for out project will include multiple solutions for the problem presented. We will have a solution that does not involve any altering of the auger itself, but rather an equation to be programmed into the operating system that will account for the decline in output. Another solution will be a proposed change to either the auger or hopper bin design that allows a linear output at increased RPMs. We will evaluate our proposed design options by assessing how well it increases the linear range, how easily it is integrated into the existing system, and the costs associated with this integration.

Modeling

There are several areas of the auger which we would like to produce models for. We will build a screw and tube that is similar to the six inch auger currently in production. Also considered for modeling is the hopper attached to the bottom of the auger. Various hopper designs may ensure that there are absolutely no voids in the proppant around the screw during high speeds. The dimension of the auger's flight and pitch within the hopper is another area that we will research and model. We will also produce an equation to improve our accuracy in measuring the expected output of the auger.

Simulation

We will enter the data, given to us from Halliburton, into a software program that will generate an equation for the data points. This equation will tell us more about the problem and help us figure out a solution. After we conduct our own experiments we will enter that data into the same software. We will then compare the two equations to show how our design(s) has changed the output.

Experiments

We will construct multiple prototypes for testing. Our control test will be conducted using an auger identical to Halliburton's six inch design, other than the length. We will shorten the auger to 5 feet long for ease of testing. This test will use a fill bin the same size as Halliburton's current design. Data will be collected by filling the auger hopper with proppant and run it till it reachs the desired speed. Once it reaches the desired speed will start collecting the sand in a second bin and will start a timer. After the test is finished we will take the proppant from the second bin and measure the weight of it. The weight of proppant moved and the amount of time taken to move it will be used to calculate a pounds per minute value. After data has been collected for the control test, the same test will be conducted using a fill bin that is larger than the current design. Next, we will re-attach the control begin testing our various designs for the auger.

Data Collection Required for Concept Generation

Test data from the augers currently being used in production has been provided to us by Halliburton. From this data, we are able to produce an equation that describes the output of the current design even outside of its linear range. This equation will give us a better idea of where design improvements need to be made. When testing our design prototypes, we will collect similar data that we can compare to the data from Halliburton's test. We will test the auger to see how many pounds per minute it delivers at various RPMs.

Development of Engineering Specifications

Using the data collected, we will alter the specifications of the current design to optimize the linearity of the auger's output. These will be the equations required to fully design our new sand screw. We will be taking into account the torque required, weight of total assembly, weight and volume of the proppant, force put on stand, force on the auger shaft, power required to drive the auger.

The *theoretical volumetric capacity* of an auger is expressed as:

$$Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n \qquad (14.1)$$

where Q_t = theoretical volumetric capacity, m^3/s

d_{sf} = screw flighting diameter, m

d_{ss} = screw shaft diameter, m

l_p = pitch length, m

n = screw rotational speed, rev/s

For the six inch auger:

$Q_t = (\pi/4)\,(5^2 - 2.375^2) in^2\,(4in)\,(300RPM) = 18237\ in^3/min = 10.55 ft^3/min$

For 100 lb/ft^3 proppant, theoretical mass output rate = 1055 lb/min

In reality the actual capacity of an auger is *considerably less* than the theoretical capacity. This results in loss of volumetric efficiency. The *volumetric efficiency* is defined as:

$$\eta_v = \frac{Q_a}{Q_t} \quad (14.2)$$

where η_v = volumetric efficiency

Q_a = actual volumetric capacity, m^3/s

For the six inch auger:

η_v = 615 / 1055 = 58%

Generally, the throughput rate is in terms of mass (or weight) per unit of time, for example t/h or kg/min, is specified. The volumetric capacity is obtained by dividing the throughput rate by the bulk density of the material.

The power requirement of an auger is expressed by the *specific power,* defined as:

$$P' = \frac{P/L}{Q_a \rho_b} \quad (14.3)$$

where P' = specific power, W s/kg m

P = power requirement, W

L = auger length, m

ρ_b = material bulk density, kg/m^3

Thus, the specific power is the power required to convey a unit mass throughput rate per unit auger length.

For the six inch auger (with 5 hp motor):

P' = (5 hp x 5 ft) / [0.2183 (ft^3/s) x 100 (lb/ft^3) x (1 slug / 32.2 slug)] = 1.48 (hp·s/slug·ft)

Table 14.1 shows a list of variables that are pertinent to the problem. These variables can be combined into ratios or dimensionless groups called the pi-terms using Buckingham's Theorem (see Chapter 1). The following equation includes the dimensionless terms:

$$\pi_1 = f\left(\frac{d_t}{d_p}, \frac{d_{sf}}{l_p}, \frac{d_{ss}}{l_p}, \frac{l_i}{l_p}, n\sqrt{\frac{l_p}{g}}, f(\Theta), \mu_1\mu_2\right) \quad (14.4)$$

where

$$\pi_1 = \frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n} \quad \text{or} \quad \frac{P/L}{Q_a \rho_b g} \quad (14.5)$$

Table 14.1. A list of variables affecting screw conveyor performance.

Symbol	Variable definition	Dimensions	Units
Q_a	actual volumetric capacity	L^3/T	m^3/s
P	power requirement	ML^2/T^3	W
d_t	tube inside diameter	L	m
d_{sf}	outside screw diameter	L	m
d_{ss}	screw shaft diameter	L	m
L	screw length	L	m
l_p	screw pitch length	L	m
l_i	exposed screw intake length	L	m
n	angular speed	1/T	rev/s
θ	angle of conveyor inclination	-	degrees
ρ_b	material bulk density	M/L^3	kg/m^3
μ_1	material-metal friction	-	-
μ_2	material-material friction	-	-
g	acceleration of gravity	L/T^2	m/s^2

The first term in the right hand side of Equation 14.5 is the ratio of the actual volumetric throughput rate to the theoretical volume swept by the screw per unit of time. This has been regarded as the volumetric efficiency of the screw conveyor. The second term in the right hand side of the above equation is the power required per unit length per unit mass flow rate of the material being conveyed. It has been defined as the specific power or the power efficiency of the conveyor. The conveyor length does not affect the volumetric efficiency.

The dimensionless terms of Equation 14.4 were used to develop prediction equations using experimental data. Published data on the performance of auger conveyors conveying wheat, oats, and shelled corn were used to develop the performance equations. These equations may be used to estimate conveyor performance for similar materials.

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\ l_p n} = (4.332\times10^{-4})\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{-0.44}\left(\frac{l_i}{l_p}\right)^{0.31}\left(f_1(\theta)\right)^{1.35}\mu_1^{-4.59}\mu_2^{-3.72}$$

(14.6)

$$\frac{P/L}{Q_a\rho_b g} = 3.54\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{0.14}\left(\frac{d_{sf}}{l_p}\right)^{-10.12}\left(\frac{l_i}{l_p}\right)^{0.11}\left(f_2(\theta)\right)\mu_2^{2.05}$$

(14.7)

where $f_1(\theta) = 1 + \cos^2\theta$ (14.8)

$f_2(\theta) = 6.94\ (1.3 - \cos^2\theta)$

θ = conveyor angle as measured from the horizontal, degrees

$0.414 > \mu_1 > 0.374$

$0.554 > \mu_2 > 0.466$

Equations 14.6 and 14.7 do not apply to materials similar to the proppant used.

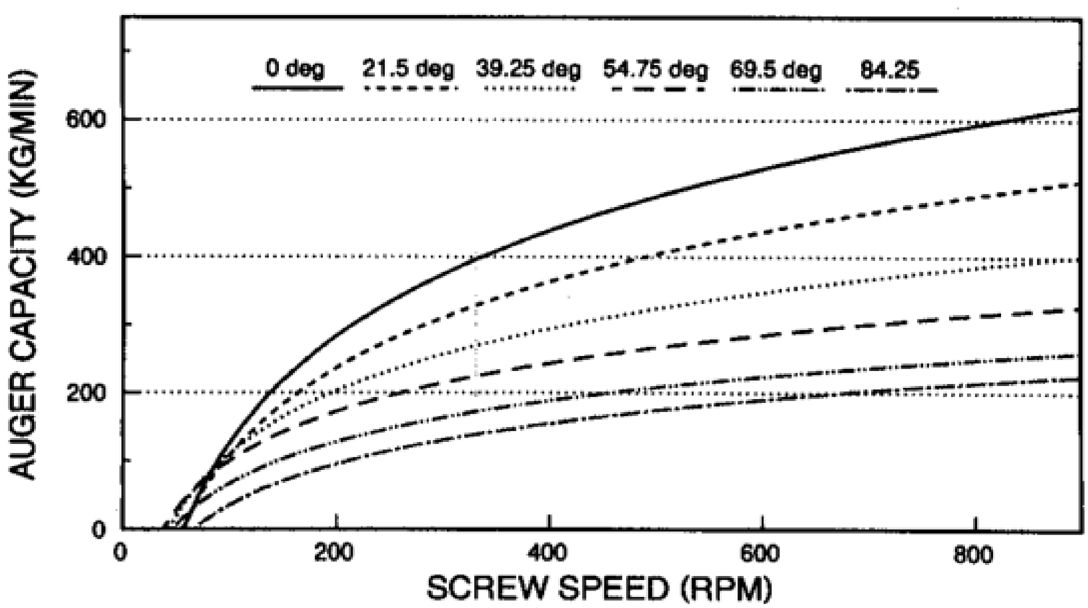


Figure 14.2 - Effect of screw speed and angle of auger inclination on conveying capacity (redrawn from Regan and Henderson, 1959).

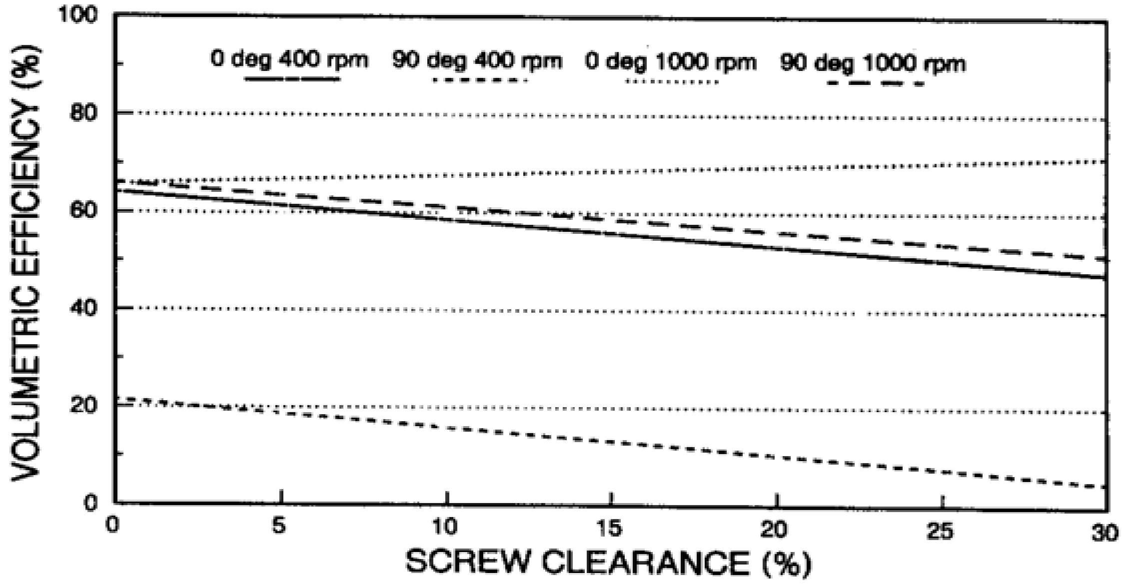


Figure 14.5 - Effect of the clearance between screw flightings and the tube inside diameter on the volumetric conveying efficiency (redrawn from Brusewitz and Persson, 1969).

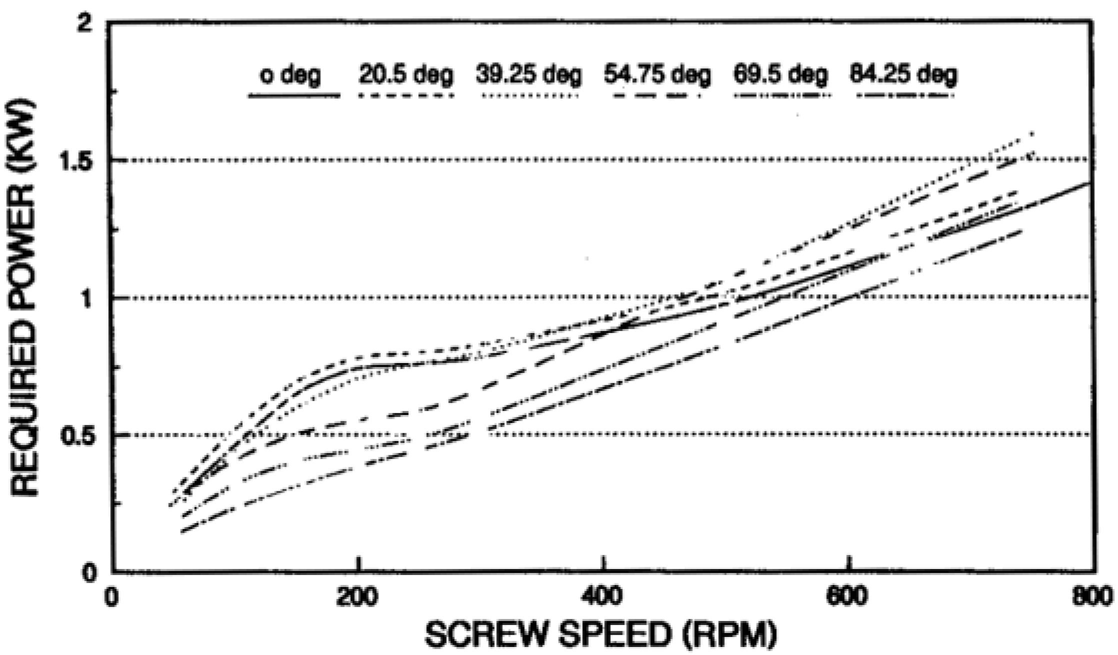


Figure 14.6 - Auger conveyor power requirements at different screw speeds and angles of inclination (redrawn from Regan and Henderson, 1959).

Equipment Needed

To build our prototype, we will need to make or purchase the following equipment. We will require two shafts for the auger as well as various flightings to go around it. We need one quarter inch thick housing for the screw. A bin to collect the sand at the intake of the auger. We will fashion a plexiglass section that will allow us to see the bottom of the bin. This will let us see if there is a fill problem in the bin. We will need a hopper for the top of the bin. We will need to assemble a driveshaft for the auger. The bottom bearing assembly for the auger will require a few different parts. We need support plates, the bearing, and also housing for the assembly. At the top of the auger, we will need assemble support for discharge section fo the auger. We will attach a output chute to the discharge section to direct the sand as it comes out. The top drive will be connected to the auger using a rolling chain coupler. We will need to assemble a stand that holds the test auger at approximately 45 degrees , which is the same angle as on the FB4K blender. Finally, we will need a 5 horsepower and will connect it to a tractor for a hydraulic variable drvie. For more details and pricing, see Appendix G.

Identifying Target Specifications

Halliburont has specified that they would like us to meet a degree of accuracy of 5%. We will choose an equation with an R^2 value above 95%. Anything less will not be worth integrating into the existing system. Our prototype will not be the same size as the 6” diameter, 11’ long auger that Halliburton uses for testing. Due to our limitations on space, time, and equiptment to manage volumes of proppant, we will use an auger 6” in diameter and 60” long. The hopper will remain the same size as on the 11’ blender.

Generating Design Concepts

Halliburton suggested that we not dismiss any part of the system when diagnosing the problem. We looked at a few different parts as possible causes for the problem at hand. One possible issue involves the feeding rate of proppant to the bottom of the auger. The bin’s current design might not allow proppant to completely fill the space around the auger every rotation. Another possible issue lies within the tube itself. Augers operate under similar concepts as a positive displacement pump. This means if the material is in the system, it will be moved as long as the system is operating properly. The decline in production at high speeds might be due to the centrifugal force in the system causing the sand to move to the outer edge of the tube, where the auger does not reach. The final part we looked at was the auger’s flighting. The pitch, angle of flighting, and shape of flighting all play a role in the productivity of the auger. Altering the flights in some fashion may cause an increase in overall productivity, as well as linearity of output. After considering all these parts as possible areas of concern, we were able to derive several options for redesigning the auger.

Option 1

Increase intake bin of the bottom of the auger

- Because its not feeding as fast as the auger can take the proppant up.
- Not filling up fast enough.
- This will allow for more proppant to fall around the auger at the entrance so there will not be voids in area where there is no proppant.
- This will be able to be done by increasing the area surrounding the bottom of the auger.

Option 2

Change the pitch and flighting of the auger

- Making the pitch longer will give the proppant more time to fall between flights in the hopper. This increase in time will allow more the proppant to entirely fill up the space between flights.
- The proppant will have more time to fill the larger area, even at high RPM.

Option 3

Add a horizontal sand screw

- It will fill the area around the bottom of the auger more efficiently.
- The horizontal screw will prevent gravity from causing the proppant to fall away from the entrance to the auger. better when it is going horizontal at first.

Option 4

Decrease the diameter of the tubing surrounding the auger

- This will give us a tighter distance tolerance between the auger and the surrounding pipe.
- This will decrease the amount of wasted sand that does not make it all the way up when the auger is running.
- This will also increase our ability to measure the accuracy of the auger
- This can also be done in reverse by increasing the size of the auger itself instead.

Option 5

Give the flighting a concave cross-section

- Concave flighting will compensate for any proppant that is lost between the auger and the tube due to centrifugal force.
- This may in return give us more of an accurate reading of how much proppant is actually being used.
- Higher carbon content makes outer edge more durable.
- See Appendix G for more information about UltraFlyte flighting.

Option 6

Removal of tube from hopper

- Remove section of auger tube that extends into hopper.
- Expose the auger to a larger volume of proppant in the hopper.
- Increase the overall volume of the hopper.
- Put a flange at the end of hopper to support tube.

Option 7

Decrease outer diameter of auger shaft

- The current design has a shaft with an outer diameter of 2 3/8”
- We believe this shaft is excessively large for use in the 6” auger.
- A smaller outer diameter will open up more space for proppant in the hopper and inside the housing.
- If the design of the 12” auger is scaled down to a 6” design, the shaft will have an outer diameter of 1 ½ inches.

Selecting Design Concept

We believe that the best possible design change is the one that increses the linearity of the auger's output while also increasing the overall rate of output and quality of auger. Each design option offers a different valid solution to the problem. At the same time, each design option presents the challenge of being integrated into the system. The design chosen should be capable of being implemented on the current product with little difficulty. Costs associated with implementing the design are also taken into consideration when choosing the best concept.

Option one assumes that the issue at hand is strictly a fill issue. At high RPMs, the auger is rotating too fast for the proppant to fall due to gravity and completely surround the auger. A larger intake bin will introduce a higher volume of proppant surrounding the bottom of the auger. This increase in volume will not increase the output of the auger at low RPMs, where the proppant has time to fully engulf the auger on each rotation. Increasing the size of the bin would require a new bin to be attached to each FB4K. Attaching the bins will entail installing a new mounting set up, and also a new intake for each auger. These integration challenges will be very costly, and will not have any effect on output until the auger nears its peak output.

Option two is a a design that only affects the pitch of flighting in the auger. A larger pitch will require less flighting per length of auger. This decrease in flighting will make more space available in the tube for the proppant to fill up. It will also give the proppant in the hopper more time per each revolution to fill the space between flights. If the same amount of proppant is being provided to the auger, the auger should be able to fill more efficiently at high speeds. Because of the increased volume of proppant being delivered per rotation, the overall output of the auger will increase. Integrating the redesigned screw into the new system would require little change to the current system. The tubing, feeding mechanism, and drive would remain the same. Removing the existing sand screw, manufacturing the new one, and installing the new one are the costs associated with this design option.

Option three involves the redesign of two pieces of the current system. First, the bin would be redesigned to be allow the proppant to enter the screw when it is parallel to the ground. Second, the screw will have to have a bending joint at the bottom of it to attach to another length of screw that will be horizontal. The current design allows gravity to pull the proppant downward, away from the point it enters the tubing. Implementing a horizontal bin would evenly distribute the proppant over a length of screw before entering the tube. Instead of the screw pulling the proppant diagonally upward towards the entrance of the tube, the proppant will be carried horizontally to the entrance of the tube. Once inside the tube, it will begin to be pulled upward. This design option will require a very complex implementation process. Attaching a horizontal fill bin to the FB4K will involve entirely redesigning the bottom of the current auger. Adding a length of screw and a new fill bin on top of it will make the FB4K longer. This will be a very costly process because of the amount of new materials required (new bin, screw, attachment to existing auger, and a means of mounting the new parts).

Option four focuses on the efficiency of the auger itself. In a perfect world, the auger would be in contact with the tube so that all proppant is being moved. In the current design, there is a half inch gap between the edges of the five inch auger and the inside of the six inch tube. This gap allows proppant to escape the flights and not be carried upward. This design option would decrease the inner diameter of the tube in order to narrow the gap between the auger and tube. This would cause a higher percentage of proppant in the tube to be carried by the auger with each rotation. The smaller tube may cause a decrease in the total amount of proppant carried, but the output will be more accurate at high speeds due to tighter tolerances. Reducing the size of the tube will call for replacing each tube on the FB4K. This process would require removing the existing tubes, attaching the new ones, and then refitting the hopper, drive, and possible bearings. To avoid replacing the tubes, the auger could be made bigger to fit the six inch tube more tightly. Doing this would avoid having to replace the tubes, and refitting the hopper.

Chemical components are often added to the proppant to avoid static build up in the blender once it is carried through the auger. Some of these chemicals will stick to the inside of the auger's housing. Occasionally, the chemicals build up due to normal use if not thoroughly cleaned on a regular basis. The demanding schedules of work in the fracking industry often don't allow for the augers to be cleaned adequately. The tolerance between the flights and the housing is to allow for a certain amount of build up to occur without causing the auger to lock up. Due to this unavoidable process, we have decided to omit option four as a viable solution.

Option five concentrates on the flighting of the auger. The current design has flights coming off the shaft straight at a right angle. Ultra Flyte's design has a concave face on the flighting of the auger. This helps increase the durability of the outer diameter of the auger by resisting the wear that traditional augers experience. The concave face also makes for faster conveying. On an 8" auger, Ultra Flyte has increased the output of standard augers by 90 bushels per hour (about 1.9 cubic feet per hour). The increase in output will be greater for the 12" auger, and smaller for the 6" auger. The concave design will improve the overall output of the design, as well as the linearity of output at high RPMs. Adding the concave design to the existing system will require the flighting of each auger to be replaced. The drive and the hopper attachment will not be effected.

Option six addresses a part of the system that we believe to be unnecessary. The housing of each auger on the FB4K extends about ten inches into the hopper. By removing this piece, proppant will be exposed to an extra ten inches of the sand screws. It will also increase the overall volume of the hopper just from being removed. A flange will be needed at the end of the hopper to support the housing. This design will not be difficult to implement with the current design, since it only involves removing one part. The cost will only be that of removing the part, and re-surfacing the area that is cut.

Option seven only pertains to the six inch auger. The current designs contain a 2 7/8" and a 2 3/8" shaft for the 12 inch and 6 inch augers, respectively. We believe that the shaft size on the 6 inch auger is excessively large for the stresses it experiences. If the shaft size is decreased on the same scale as the flighting, a 1 ½" shaft on the 6 inch auger should be sufficient. A smaller shaft will provide more area for proppant to fill inside the auger tube. This will increase the overall output as well as the accuracy at high RPM. Decreasing the shaft size will be difficult to implement on existing FB4K blenders because it requires new flighting in addition to a new shaft. The drive mechanism will also need to be altered to fit the new shaft.

We believe that options five and seven fit our design criteria the best. They increase the overall system in several ways, and do not have many issues with implementation. The concave flighting will increase the durability of the auger. Less wear on the auger will save money that can be spent on other parts. The concave flighting will increase the output at all RPMs. The concave flighting will have a smaller shaft, part of the option seven design. The part of the auger housing that exetends into the hopper will also be removed. A combination of the smaller shaft, tube removal, and Ultra Flyte flighting will result in a higher range of linear output. We will test each viable option independently first, then (time permitting) we will combine several design options to see if a combination of two (or more) provides the best solution.

Project Management

The project is managed using Microsoft Project software. The project management software program allows us to develop an overall plan by scheduling tasks, assigning resources to those tasks, managing the budget for the resources, and splitting up the workload for the tasks. Tasks range in significance from "optimizing auger ouput" to "comparing equations." The program allows us to account for every task required for the completion of this project, no matter how big or small the task may be. This program has proved to be very valuable in scheduling the timetables for our deliverables.

Deliverables

The deliverables for this project are divided into two sections: fall and spring. In the fall, we were given test data from Halliburton to analyze. After analyzeing this data, we will deliver an equation for a best fit line for the test data. We will also propose multiple design concepts that could possibly correct the nonlinearity region of the data. We will then present our findings and designs.

In the spring, we will manufacture a prototype of a finalized design and conduct tests on the prototype. The tests will be conducted similar to the original testing done by Halliburton. The new test data will be analyzed and compared to original test data. A new equation will be derived from the new data to be compared to the original equation.

Budget

We have been provided with some monetary assistance for this project directly from Halliburton. They would like to keep the budget between $5-10k. From this we will purchase the nessesary equipment to manufacture a scaled working replica of Haliburtons current design with some modifications that will lineraize the output of their design. If our experiments prove to be successful, the investment in our research will provide Halliburton with data that suggests how they can improve their fracking process. The improvements will make their process more efficient and profitable. For more details, see Appendix G.

Cost Analysis

We were paired with three Agriculture Economics students to help us analyze the financial benefits of our research. Becca Baca, Chris Willis, and Aaron Hoerst (Oil Field Research Group) provided us with the following cost analysis:

"Given our $10,000 budget, OFCG has estimated the feasibility of optimizing the sand screws on a hydraulic fracture blending system. We have used the cost and amount of proppant saved as a measure of return on investment. With the incorporation of our optimized system according to Halliburton's implementation plan, there is no additional variable cost which may include implementation, labor, and/or maintenance. We have assumed that Halliburton's field operations perform at a level competitive with industry averages, and that the optimized system designed by our engineers will be capable of saving a given percentage of the excess proppant used in the fracturing process.

The engineering team is designing a single sand screw intended to increase the accuracy of proppant introduced into the blending system. A spreadsheet created by the business team allows us to input the estimated price of frac sand; the percent of frac sand saved from using the optimized sand screw; and the amount of frac sand used in a specific well, which ultimately exhibits the cost savings from implementing the enhanced sand screw. The excel spreadsheet also permits Halliburton to enter the exact amount of research and development that was spent on enhancing the sand screw. With this information, along with the depreciation expense per year, we were able to determine the return on investment, the initial investment and the percentage of proppant cost saved. We can also estimate the net present value, internal rate of return and payback period of optimizing the blending system. Payback period will be calculated in jobs per blender rather than years.

	A	B	C
1	MENU		
2	FORWARD TO DEPRECIATION		
3	FORWARD TO OPERATIONS SUMMARY		
4	FORWARD TO RETURN ON INVESTMENT		
5	BACK TO INTRODUCTION		
6			
7			
8			
9	INPUT CAPITAL STRUCTURE AND		
10	EXPENSE INFORMATION		
11	Other		
12	Expense Inflation Rate	1.00%	
13	Output price inflation rate	1.00%	
14	Discount rate for NPV calculation	4.00%	
15			
16	Corresponding Input Value	% of Proppant Saved	
17	2	0.1%	
18	3	0.2%	
19	4	0.3%	
20	5	0.4%	
21	6	0.5%	
22	7	0.6%	
26	8	0.7%	
27	9	0.8%	
28	10	0.9%	
29	11	1.0%	

	D	E	F	K	L
9	INPUT PRODUCTS, INITIAL VOLUME, MARGIN PER UNIT AND				
10	ANTICIPATED PROPPANT SAVINGS GROWTH			Research and Development	
11	Product Name	Sand Screw		Product	FC/unit
12	Units	Pounds		Sand Screw	$ 5,000
13	Price of Proppant per Pound	$ 5.00			
14	Proppant Used in Well (250k-1mil. 50,000 increments)	350,000			
15	Input Value For Percent of Proppant SavedSaved	3	0.2%		
16	Initial Proppant Saved	700			
17	$ Amount Saved/Well	$ 3,500			

Figure 7: Cost Analysis input values and savings per well **Source: OFCG Cost Analysis Spreadsheet**

For example, we can predict the enhanced system will save 0.2% of proppant per well, an average of 350,000 pounds of proppant used per fracture, and the cost of proppant at $5.00 per pound. Using these numbers and a selected discount rate of 4.00%, we have calculated a savings of $3,500 per fracture, on proppant cost alone. These variables can be adjusted as Halliburton sees fit.

Halliburton's budget for prototyping (research and development), which will be the investment cost, cannot exceed $10,000. In this example, we use $5,000.

Using an initial investment of $5,000, and proppant values as stated above, the net present value of this project given a 5 fracture analysis is $10,884. The investment would

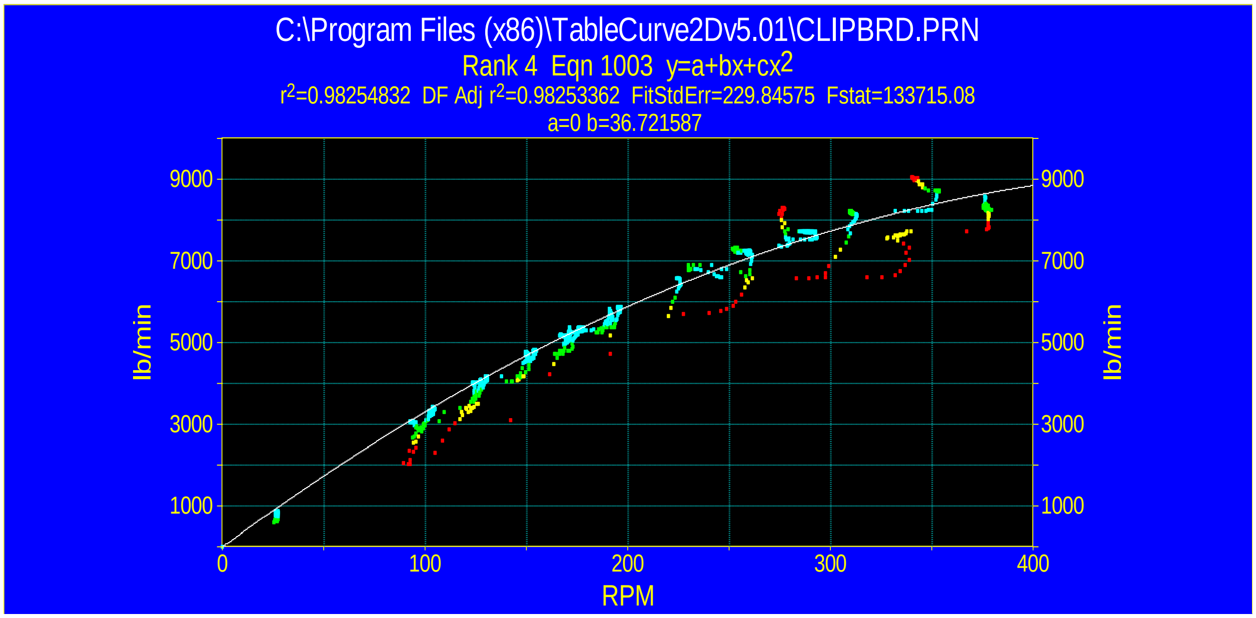
	A	B	C	D	E	F	G	H
1	MENU							
2	BACK TO INPUTS							
3	BACK TO OPERATION SUMMARY							
4								
5	This sheet summaries the feasibility of the project. It provides net present value, benefit cost ratio and internal rate of return							
6	The only input is the discount rate.							
7								
8	Discount Rate	4.00%						
9								
10	Year		0	1	2	3	4	5
11	Gross Margin			$3,500	$3,535	$3,570	$3,606	$3,642
12	Discount Factor		1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
13	PV of Income		$0	$3,365	$3,268	$3,174	$3,082	$2,994
14								
15	Total Expense		$5,000	$0	$0	$0	$0	$0
16	Less Depreciation and Term Interest			$0	$0	$0	$0	$0
17								
18	Cash Expenses		$5,000	$0	$0	$0	$0	$0
19	Discount Factor		1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
20	PV of Expenses		$5,000	$0	$0	$0	$0	$0
21								
22	Benefits Less Costs		($5,000)	$3,500	$3,535	$3,570	$3,606	$3,642
23	PV Benefits Less PV Costs		($5,000)	$3,365	$3,268	$3,174	$3,082	$2,994
24								
25	Total PV of Income	$15,884						
26	Total PV of Expenses	$5,000						
27	Net Present Value	$10,884						
28	Internal Rate of Return	64.98%						
29	PV Benefit/PV Cost Ratio	3.18						
39	Payback Period (years)	1						
40	(payback period only displayed if less than 10 years)							

Figure 8: Cost Analysis cash flows and projects acceptance calculations, assuming an initial investment of $5,000 **Source: OFCG Cost Analysis Spreadsheet**

be paid back in under two years, given the savings as calculated in Figure 7. The profitability of investment, or internal rate of return, is 64.96%."

Appendix A: Curve Equations

Curve 1



Rank 4 Eqn 1003 $y=a+bx+cx^2$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9825483240	0.9825336216	229.84575243	133715.08070

Parm	Value	Std Error	t-value	95% Confidence Limits		P>|t|
a	0.000000000					
b	36.72158658	0.074298521	494.2438448	36.57588990	36.86728325	0.00000
c	-0.03643035	0.000282796	-128.822063	-0.03698490	-0.03587579	0.00000

Area Xmin-Xmax	Area Precision		
1981921.1014	1.147239e-19		
Function min	X-Value	Function max	X-Value
5.788416e-09	1.576298e-10	8690.4945787	379.65000920
1st Deriv min	X-Value	1st Deriv max	X-Value
9.0600247373	379.65000920	36.721586579	1.576298e-10
2nd Deriv min	X-Value	2nd Deriv max	X-Value
-0.072860691	254.36584427	-0.072860691	216.40087141
Soln Vector	Covar Matrix		
Direct	LUDecomp		
r^2 Coef Det	DF Adj r^2	Fit Std Err	Max Abs Err
0.9825483240	0.9825336216	229.84575243	1504.1723357
r^2 Attainable			
0.9988934580			

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	7.0640433e+09	1	7.0640433e+09	133715	0.00000
Error	1.2546904e+08	2375	52829.07		
Total	7.1895124e+09	2376			
Lack Fit	1.1751354e+08	1026	114535.62	19.4216	0.00000
Pure Err	7955497.2	1349	5897.3293		

Date	Time	File Source
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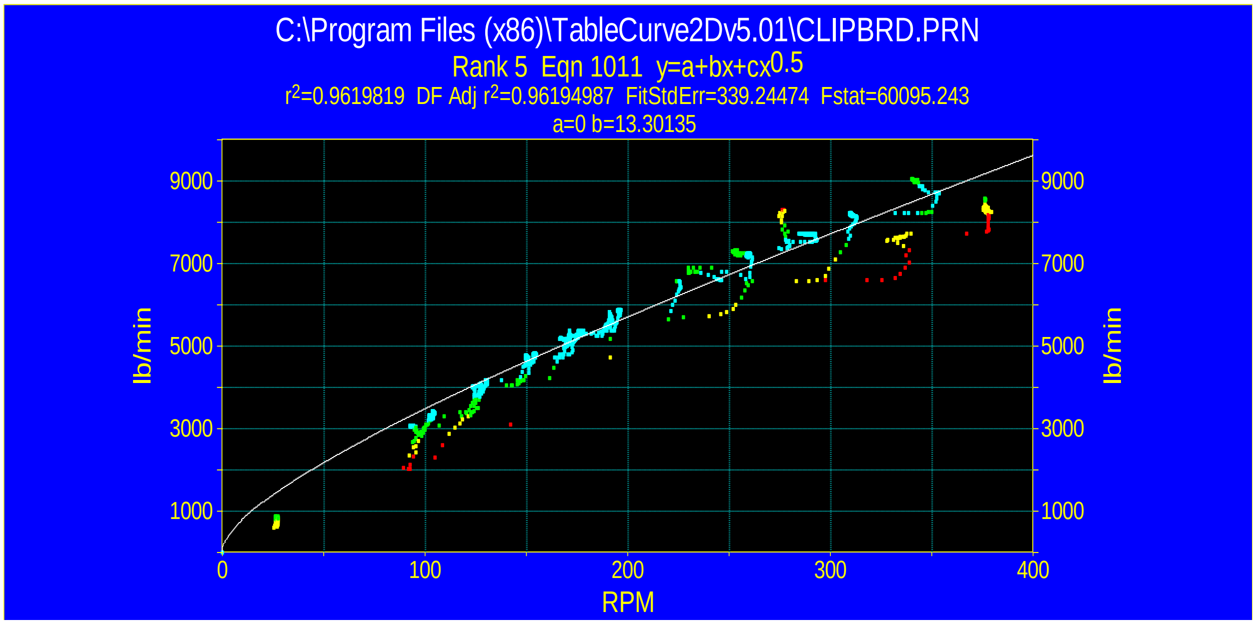
Curve 2



Rank 5 Eqn 1011 $y=a+bx+cx^{0.5}$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value
0.9619818990	0.9619498702	339.24473907	60095.242737

Parm	Value	Std Error	t-value	95% Confidence Limits		P>|t|
a	0.000000000					
b	13.30134967	0.183407994	72.52328201	12.94169331	13.66100602	0.00000
c	215.8282005	2.712092509	79.57995525	210.5098866	221.1465145	0.00000

Area Xmin-Xmax	Area Precision		
2022957.9025	2.645516e-07		
Function min	X-Value	Function max	X-Value
0.0027097404	1.576298e-10	9255.1857398	379.65000920
1st Deriv min	X-Value	1st Deriv max	X-Value
18.839777316	379.65000920	8595273.4654	1.576298e-10
2nd Deriv min	X-Value	2nd Deriv max	X-Value
-2.72641e+16	1.576298e-10	-0.007294123	379.65000920
Soln Vector	Covar Matrix		
Direct	LUDecomp		
r^2 Coef Det	DF Adj r^2	Fit Std Err	Max Abs Err
0.9619818990	0.9619498702	339.24473907	1677.0637338
r^2 Attainable			
0.9988934580			

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	6.9161808e+09	1	6.9161808e+09	60095.2	0.00000
Error	2.7333161e+08	2375	115086.99		
Total	7.1895124e+09	2376			
Lack Fit	2.6537611e+08	1026	258651.18	43.859	0.00000
Pure Err	7955497.2	1349	5897.3293		

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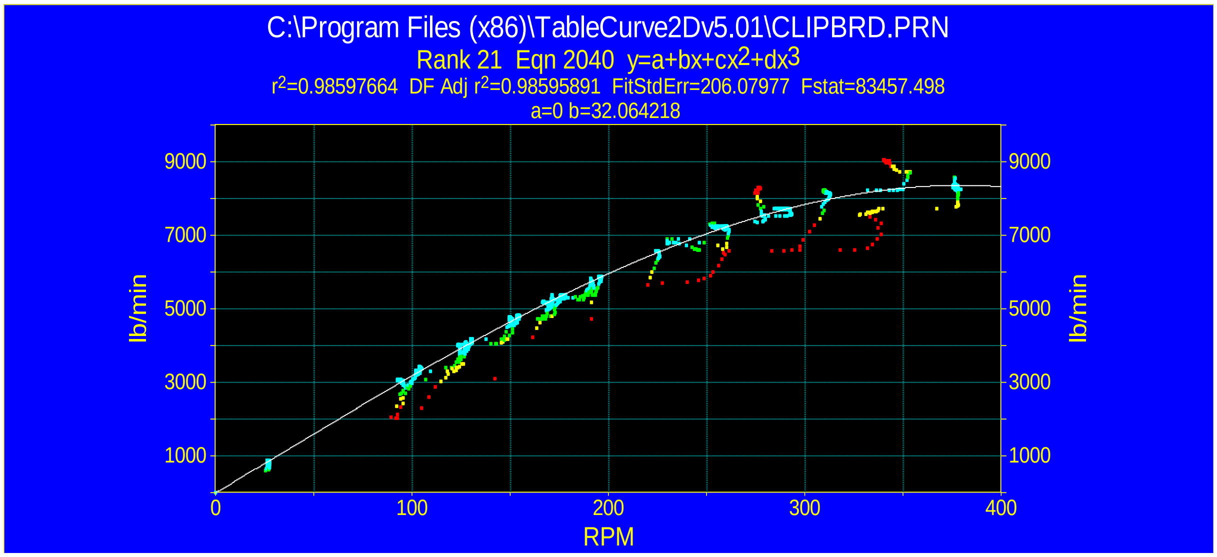
Curve 3



Rank 21 Eqn 2040 $y=a+bx+cx^2+dx^3$

r^2 Coef Det	DF Adj r^2	Fit Std Err	F-value		
0.9859766431	0.9859589145	206.07976659	83457.497885		

Parm	Value	Std Error	t-value	95% Confidence Limits		P>|t|
a	0.000000000					
b	32.06421800	0.204479447	156.8090020	31.66324122	32.46519479	0.00000
c	0.005447245	0.001756703	3.100834879	0.002002415	0.008892075	0.00195
d	-8.3828e-05	3.47963e-06	-24.0910089	-9.0651e-05	-7.7004e-05	0.00000

Area Xmin-Xmax	Area Precision		
1974759.3829	0.0000000000		
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2nd Deriv min	X-Value	2nd Deriv max	X-Value
-0.180056924	379.65000920	0.0108944898	1.576298e-10
Soln Vector	Covar Matrix		
GaussElim	LUDecomp		
r^2 Coef Det	DF Adj r^2	Fit Std Err	Max Abs Err
0.9859766431	0.9859589145	206.07976659	1505.9864569
r^2 Attainable			
0.9988934580			

Source	Sum of Squares	DF	Mean Square	F Statistic	P>F
Regr	7.0886913e+09	2	3.5443456e+09	83457.5	0.00000
Error	1.008211e+08	2374	42468.87		
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Nov 12, 2012	8:03:22 PM	t:\teaching\snrdsgn\senior design 2012-

Appendix B: Patents

US006193402B1

(12) **United States Patent**
Grimland et al.

(10) **Patent No.: US 6,193,402 B1**
(45) **Date of Patent: Feb. 27, 2001**

(54) **MULTIPLE TUB MOBILE BLENDER**

(76) Inventors: **Kristian E. Grimland**, 37279 Timber Dr., Elizabeth; **Timothy Lloyd Anderson**, 20031 Road 17, Fort Morgan, both of CO (US) 80701

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/165,649**

(22) Filed: **Oct. 2, 1998**

Related U.S. Application Data

(60) Provisional application No. 60/077,170, filed on Mar. 6, 1998.

(51) **Int. Cl.**^{7} **B01F 15/02**

(52) **U.S. Cl.** **366/14**; 366/27; 366/33; 366/165.5

(58) **Field of Search** 366/10, 14, 15, 366/27, 28, 33, 34, 42, 165.3, 165.5, 181.6, 606; 166/177.5, 90.1

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,660,415	*	11/1953	Hawes .
3,050,159		8/1962	Paulus et al. .
3,295,698		1/1967	Ross et al. .
4,159,180		6/1979	Cooper et al. .
4,239,396	*	12/1980	Arribau et al. .
4,448,535	*	5/1984	West .
4,453,829		6/1984	Althouse, III .
4,490,047		12/1984	Stegemoeller et al. .
4,802,141		1/1989	Stegemoeller et al. .
4,850,701		7/1989	Stegemoeller et al. .
4,850,702	*	7/1989	Arribau et al. .
4,913,554		4/1990	Bragg et al. .
4,915,505	*	4/1990	Arribau et al. .

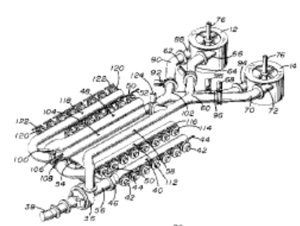
* cited by examiner

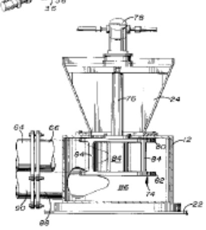
Primary Examiner—Tony G. Soohoo
(74) *Attorney, Agent, or Firm*—Pittenger & Smith, P.C.

(57) **ABSTRACT**

An improved oil and gas well servicing apparatus for blending and delivering a slurry of fracturing fluid and particulate matter at constant flow rate and pressure to a downhole pump is disclosed. Multiple blending tubs are mounted on a trailer or skid and are manifolded together in a slurry discharge manifold. The slurry discharge manifold combines the slurry discharged by the blending tubs and incorporates pipe sections of equal length to connect the blending tubs to the manifold. It is believed that the slurry discharge manifold and equal length piping provide balanced pressure drop between the individual blending tubs and creates a constant outlet pressure from the slurry discharge manifold. A fluid intake manifold may also be included to distribute fracturing fluid to the blending tubs. Hose connectors on each of the manifolds are provided on both sides of the apparatus for convenient operation from either side. A conveyer system delivers particulate matter, such as sand, to a distribution bin located above the blending tubs. A source of fracturing fluid may be attached to a hose connector on the fluid intake manifold. The blending tubs utilize a variable drive means placed above each blending tub and suspending an impeller in the blending tub and rotating it about a vertical axis. Thus, a plenum space is provided between the impeller and the bottom of the tub. A tangential outlet is located adjacent to the plenum space and carries the slurry out of the blending tub and into the slurry discharge manifold.

18 Claims, 6 Drawing Sheets





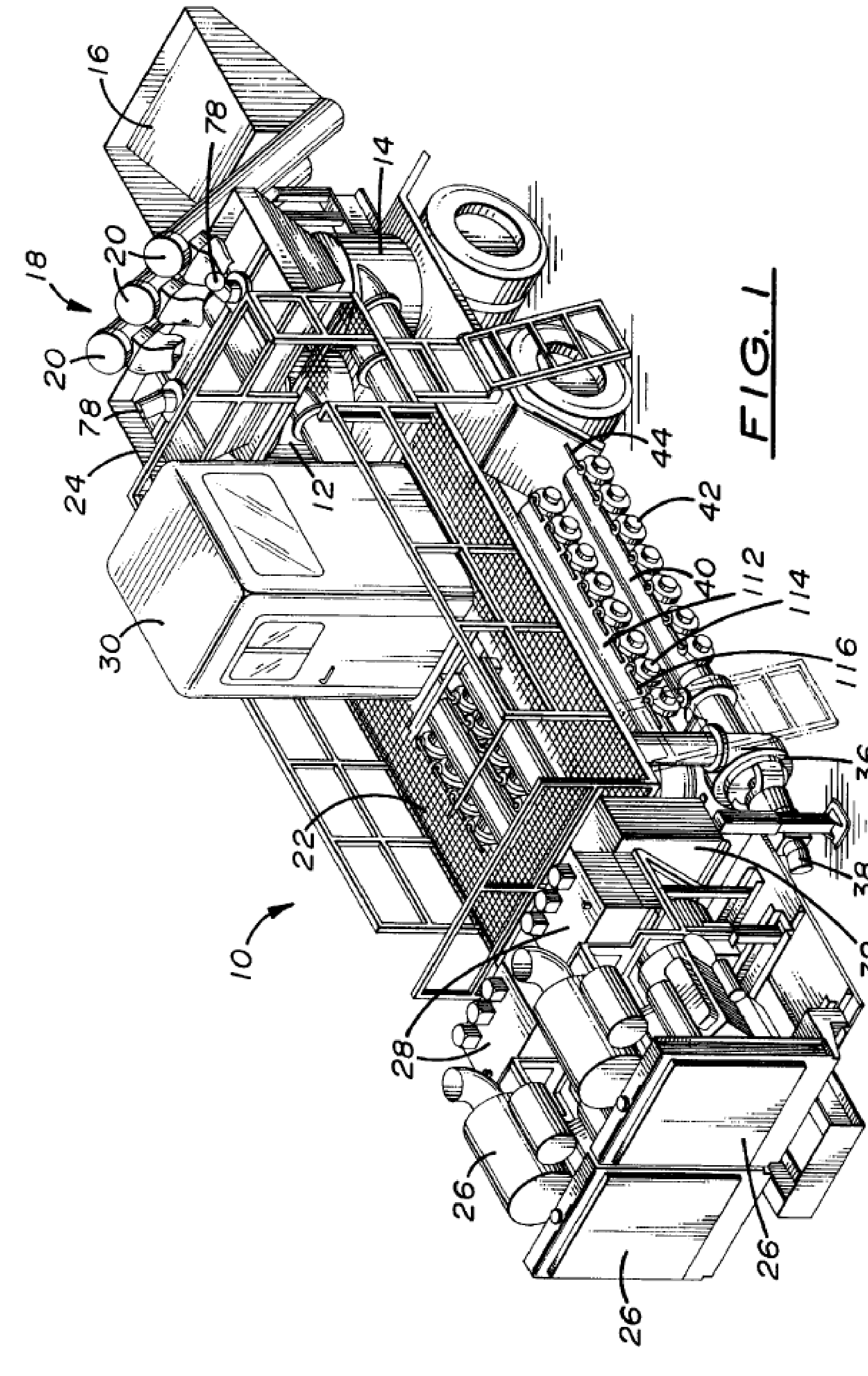

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FIG. 1

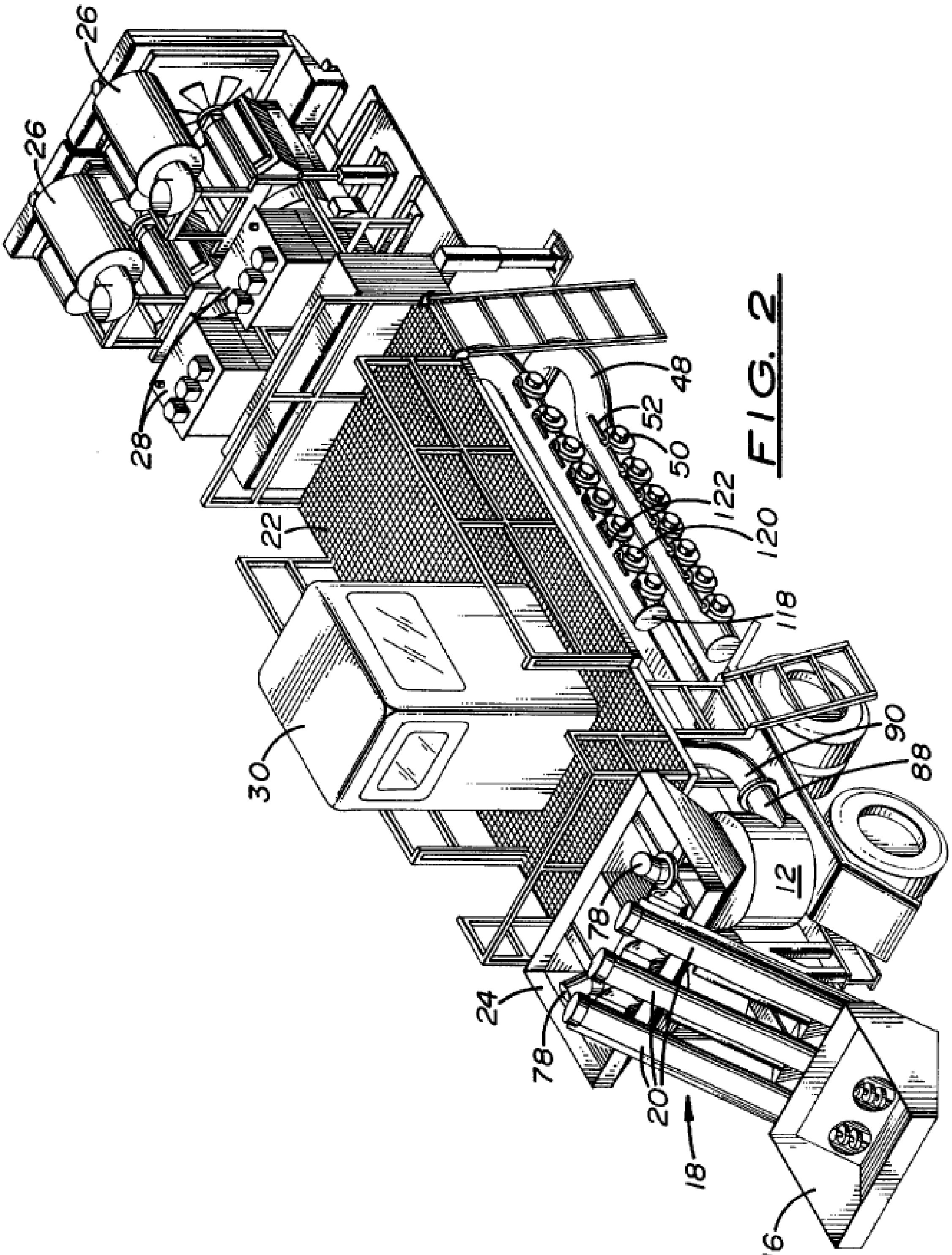

FIG. 2

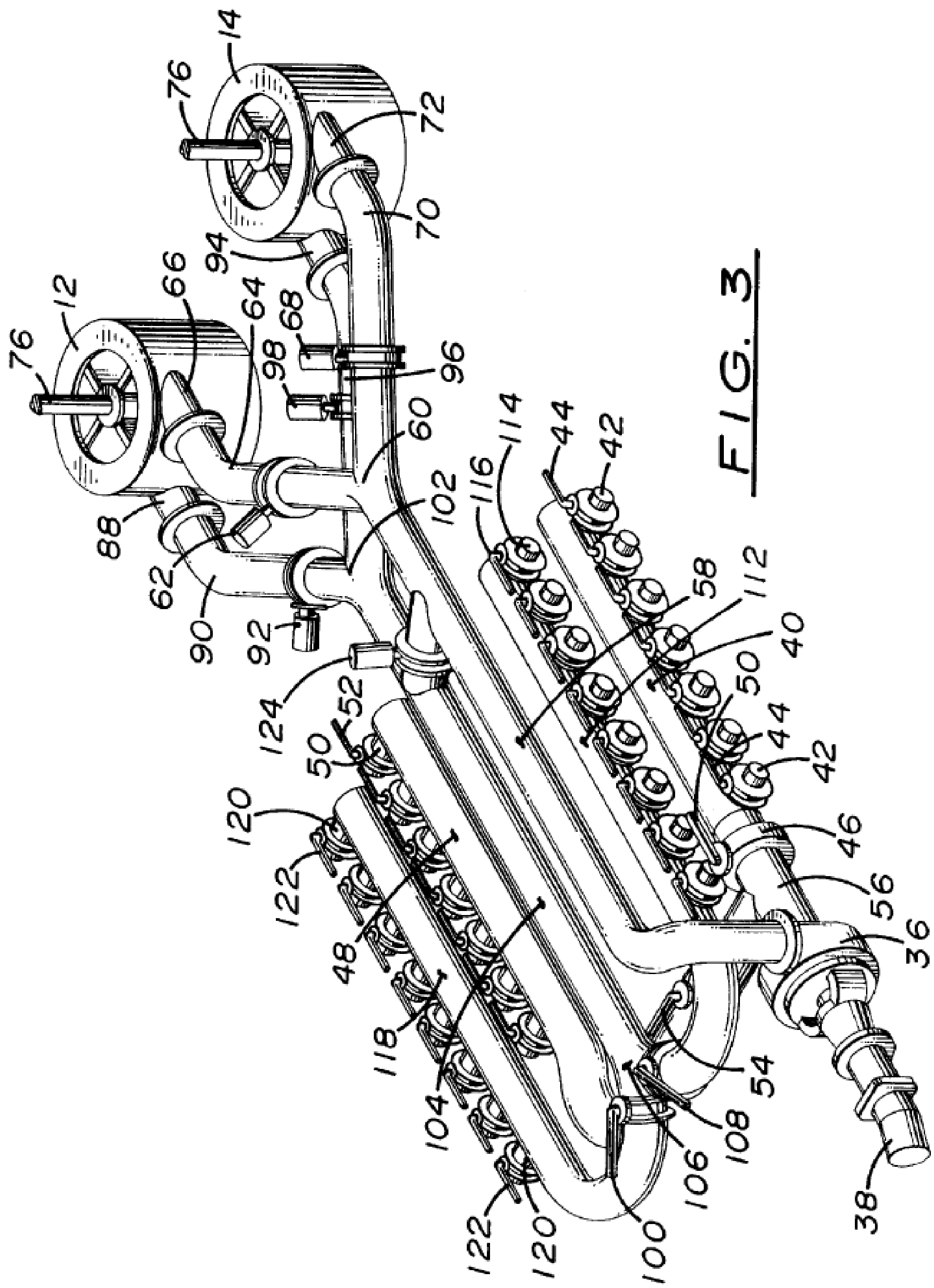

FIG. 3

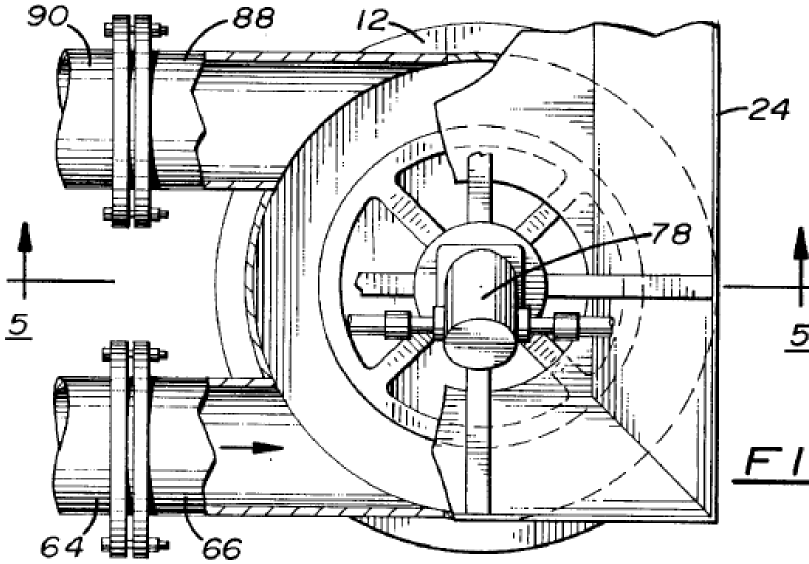

FIG. 4

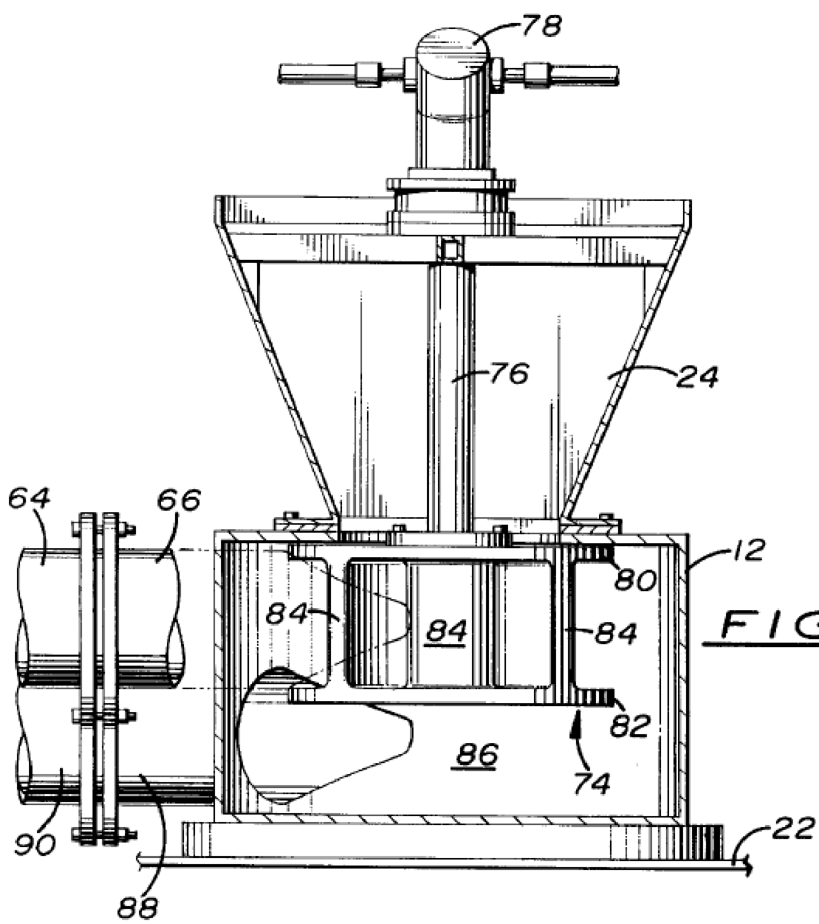

FIG. 5

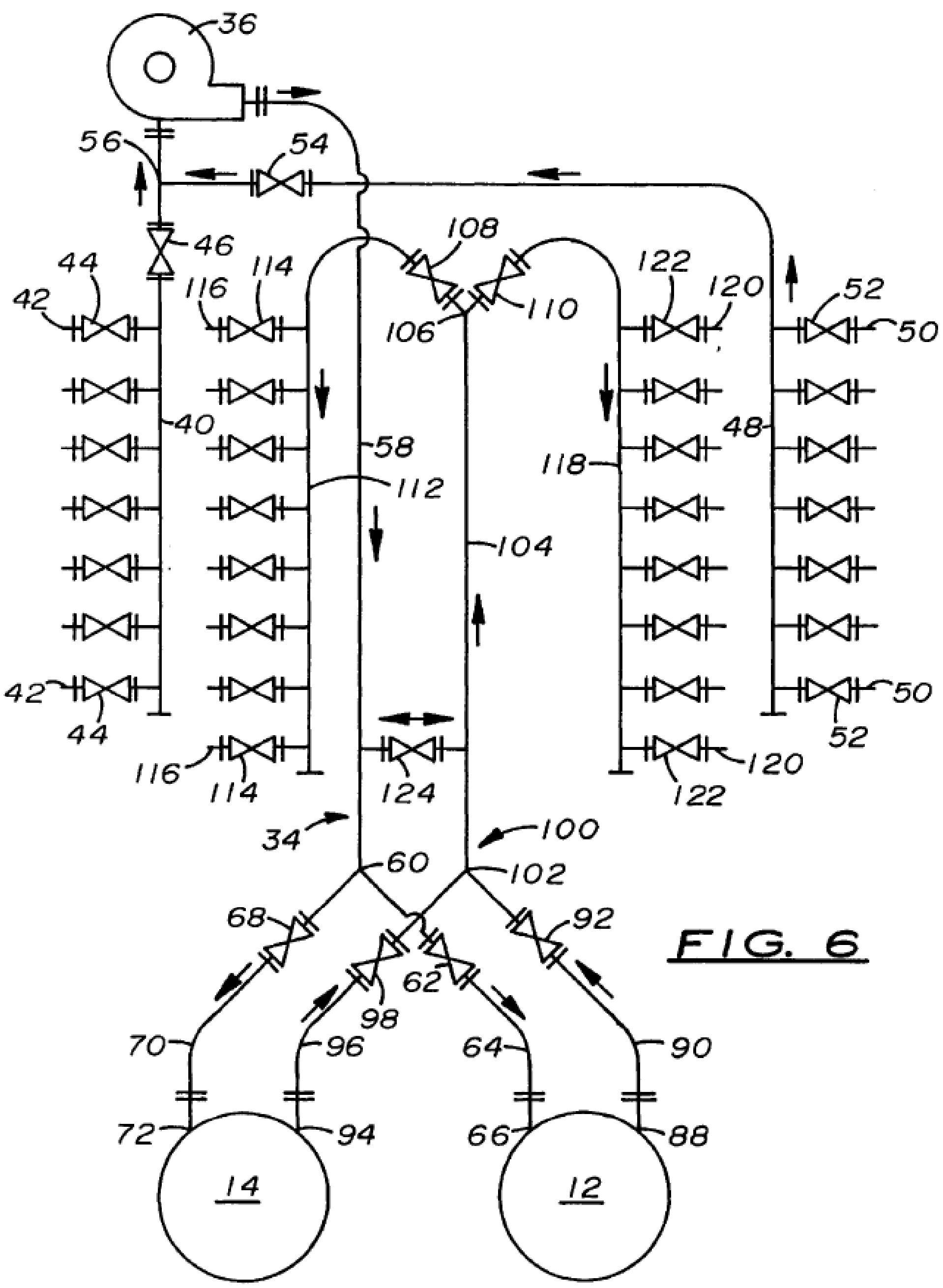
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FIG. 6

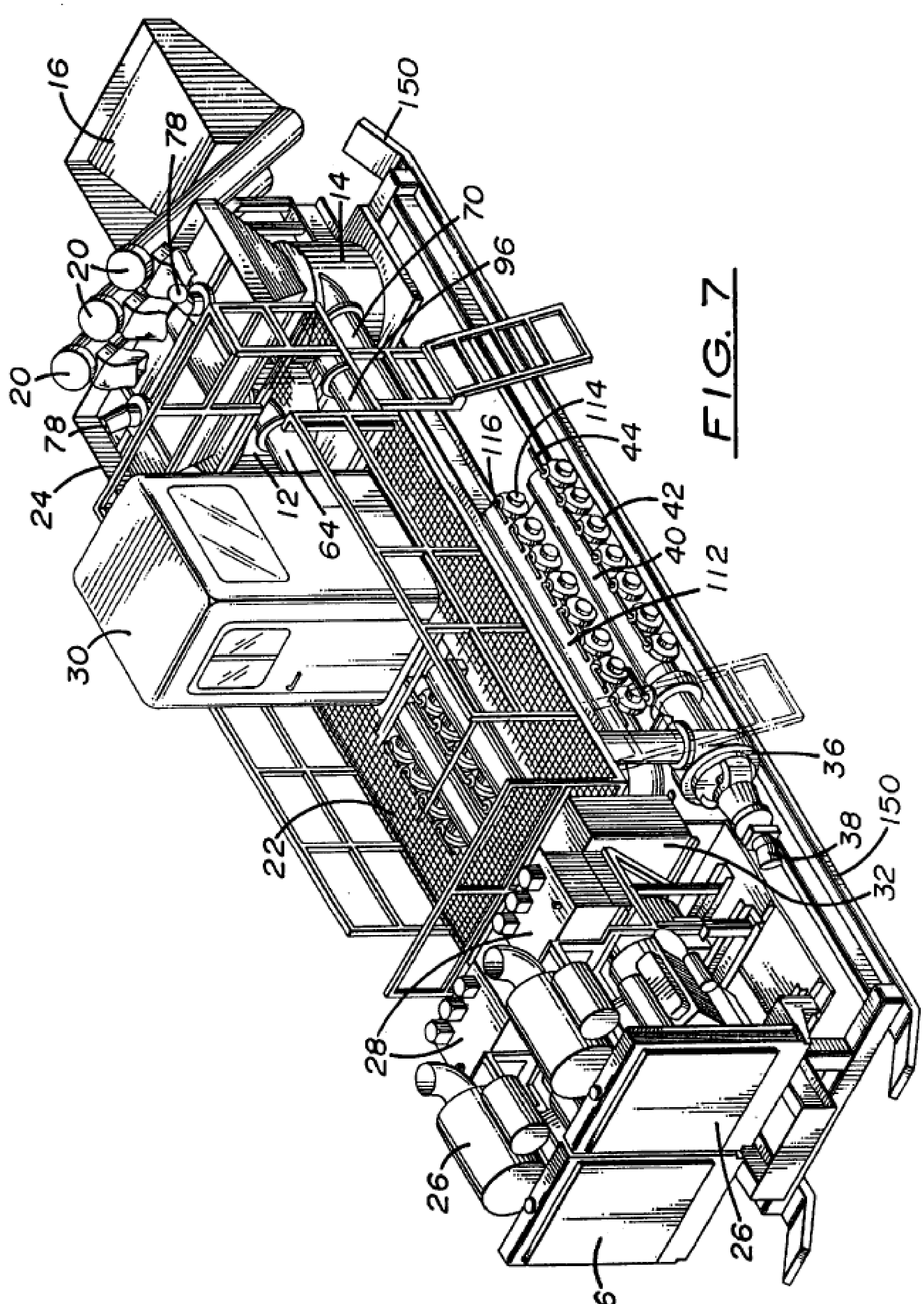
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FIG. 7

MULTIPLE TUB MOBILE BLENDER

REFERENCE TO RELATED PATENTS

This application claims the benefit of U.S. provisional patent application Ser. No. 60/077,170, filed Mar. 6, 1998.

FIELD OF THE INVENTION

The present invention relates to a blending apparatus. Specifically, the present invention relates to a blending apparatus used in well fracturing operations. More specifically, the present invention relates to a blending apparatus having multiple mixing tubs.

BACKGROUND OF THE INVENTION

To increase the production of an oil, gas, geothermal, or other type of well, the producing zone of the geological formation surrounding the well is fractured to allow the desired fluids to flow more freely through the formation and into the well. Fluid is pumped into the formation under high pressure to fracture the producing zones. However, if fracturing fluid is pumped into the formation during the fracturing operation without some accompanying solid, the geological formation pressures will cause the fractured areas of the formation to close when the pumping of fracturing fluid stops, thus restricting the flow of the oil or gas.

A slurry of particulate material, such as sand blended with the fracturing fluid, may be forced into the fissures in the geological formation to keep the formation open after the slurry has been pumped into the well. Well servicing equipment incorporates blending apparatus to mix the particulate material with the fracturing fluid. The blender discharges the slurry to a high pressure, downhole pump that injects it into the well and into the producing zones. It is important that the discharge pressure of the blender remains constant to prevent the downhole pump from cavitating, a condition in which inlet fluid flow is reduced or air is passed through the pump and downhole pressure is lost. When cavitation occurs in the downhole pump, the fracturing operation fails.

It is desirable to use multiple blending tubs in the blending and fracturing operations. Multiple blending tubs increase the flow rate and provide a failsafe backup system in the event that one of the tubs fails. However, because of cavitating and other downhole pump problems, it has been difficult to use multiple tubs simultaneously. It is crucial to a cost effective fracturing operation that a high flow rate of slurry is reliably delivered at a relatively constant pressure to the downhole pumping equipment.

FORMATION DISCLOSURE STATEMENT

The Stegemoeller patents (U.S. Pat. No. 4,490,047, U.S. Pat. No. 4,802,141, U.S. Pat. No. 4,850,701 and U.S. Pat. No. 4,913,554) disclose a structure which combines a single mixing tub mounted on a vehicle and having in conjunction an engine for driving hydraulic pumps, additive tanks for use in producing the slurry mixture from the mixing tub, and a control station for operating and monitoring the operation of the system. Throughout these patents, there is considerable discussion concerning the shape and size of the mixing tub. However, there is no teaching in any of the Stegemoeller et al. patents of manifolding multiple blending tubs together to provide a constant outlet pressure.

The Cooper patent (U.S. Pat. No. 4,159,180) discloses a mixing tub mounted on an articulated truck bed. The purpose behind this mechanism is to allow the mixing tub to be rolled off of the truck chassis so that it is resting upon the

ground. It is stated that this lower position for the mixing tub allows the tub to be charged with conventional loading equipment instead of having to provide a loading mechanism on the truck itself. The entire system is returned to the truck chassis for transportation purposes. The Cooper patent teaches a single mixing tub and does not disclose the use of multiple tubs.

The Althouse patent (U.S. Pat. No. 4,453,829) discloses a type of mixing tub which utilizes a special impeller for the mixing and blending of the ingredients to form the outlet slurry. This embodiment uses a relatively flat casing with a first impeller having a slinger and a second impeller fastened to a vertical shaft. The second impeller is positioned beneath the slinger portion. The slinger has a toroidal shape which is stated to provide a good pressure balance within the fluid composition for circulating and mixing within the casing. The mixing tub utilizes a reverse centrifugal pump. This mixing tub is used in the servicing of oil wells. The Althouse patent does not teach the use of multiple blending tubs.

The Paulus et al. patent (U.S. Pat. No. 3,050,159) and the Ross et al. patent (U.S. Pat. No. 3,295,698) disclose mobile mixing systems. Both of these patents, however, are directed to batch plants usually for the mixing and pouring of concrete. The Paulus et al. patent discloses a self-erecting portable mixing plant which is transported to the site on a trailer type structure. Upon reaching the site, the structure is erected or elevated into position with the mixer and loading distribution bin elevated to a considerable height to allow the contents of the mixer to be dumped directly into a hauling vehicle. The Ross et al. patent also shows a trailer mounted batch plant whereby a concrete silo is erected into a vertical position with conveyers used for automatically charging a portable mixer with the proper ingredients for concrete. These last two patents are not directly on point, but disclose various types of trailer mounted structures which are used for mixing purposes. These references do not disclose multiple tubs manifolded together to allow the use of two or more tubs simultaneously.

SUMMARY OF THE INVENTION

The present invention provides an improved well servicing apparatus for blending and delivering a slurry of fracturing fluid and particulate matter at a constant flow rate and pressure to a downhole pump. Multiple blending tubs are mounted on a trailer, skid, or other type of supporting vehicle or structure and are manifolded together with a slurry discharge manifold. Pipe sections of equal length connect the blending tubs to the slurry discharge manifolds. The slurry discharge manifold and equal length pipe sections provide balanced pressure between the individual blending tubs. Connections to the manifold are provided on both sides of the support structure for convenient operation from either side. A fluid intake manifold on either or both sides of the apparatus may be included to deliver fracturing fluid to the blending tubs. A source of fracturing fluid, such as a tanker truck, is attached to one or more connections on the fluid intake manifold. A conveyer system delivers particulate matter, such as sand, to a distribution bin located above the blending tubs.

Each blending tub may be cylindrically shaped and powered by a rotating impeller attached to and suspending from a vertical drive shaft. Particulate matter is fed by gravity through the distribution bin into an opening in the top surface of each blending tub. Fracturing fluid is introduced into the blending tub from a tangential inlet located on the upper portion of the blending tub. A plenum space is provided in the tub directly below the rotating impeller. As the fracturing fluid and particulate matter gravitate downward through the tub, they are mixed to form a slurry which exits through a tangential discharge outlet located on the lower portion of the tub adjacent to the plenum. Control valves are located near the inlet and outlet of each blending tub. These valves are used primarily to isolate a blending tub when it is not in use.

Because the inlet and outlet piping to the individual tubs are identical on each tub, the pressure drop in these pipes are relatively the same. This characteristic allows the tubs to automatically balance the pressure within the tubs and manifolds and thus provide a constant outlet pressure to the downhole pump. This self-balancing of the pressures within the tubs and thus the outlet manifold is a critical and unique feature of the present invention.

The start up operation of the blending tubs proceeds as follows. The slurry is mixed in one blending tub with the impeller rotating at 600 rpm or more and the inlet and outlet valves open. The suction pump is operated to provide a pressure of between approximately 25 psi and 38 psi. The impeller of the second tub is brought up to a speed of approximately 600 rpm or more before being filled with fracturing fluid and introducing particulate matter. Once the fracturing fluid and particulate matter begin mixing, the inlet and outlet control valves are opened. The outlet pressures of the two tubs balance and equalize in the outlet manifold, thus providing constant pressure to the downhole pump.

Other features and advantages of the present invention will become apparent from the following detailed description of the invention when it is considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** and **2** are perspective views of opposite sides of the present invention mounted on a trailer;

FIG. **3** is a perspective view of the blending tubs and piping for the fluid intake manifold and slurry discharge manifold;

FIG. **4** is a plan view of the blending tub, drive unit, and associated inlet and outlet pipe sections;

FIG. **5** is a partial side view of the blending tub, distribution bin, and drive unit, showing the lower cavity area;

FIG. **6** is a diagram in schematic form illustrating the fluid intake manifold and slurry discharge manifold; and

FIG. **7** is a perspective view of an alternative embodiment of the apparatus shown mounted on a skid.

DETAILED DESCRIPTION OF THE INVENTION

As shown in FIGS. **1** and **2**, blending tubs **12**, **14** are mounted on a trailer **10** or skid **150** (FIG. **7**). A conveyer system **18** may be used to deliver particulate matter, such as sand, from a hopper **16** to a distribution bin **24** located above the blending tubs **12**, **14**. The conveyer system **18** may incorporate a plurality of augers **20**, each enclosed by a cylindrical sleeve, and capable of feeding particulate matter from a hopper **16** to the distribution bin **24** through a positive displacement screw. The augers **20** may be powered simultaneously or separately, depending on the required amount of particulate matter. The speed of each auger **20** may be independently controlled, thus providing adjustment and control over the amount of particulate matter that is fed to each of the blenders. A slidable or otherwise movable baffle may be provided within the distribution bin **24** for diverting and controlling the flow of particulate matter to the individual blending tubs **12**, **14**.

Two large diesel engines **26** may be used to power the apparatus. Each engine **26** powers a separate hydraulic pump **28** and reservoir **32**, which drives an individual blending tub, and one or more augers **20** in the conveyor system **18**. The hydraulic pumps **28** may drive the drive unit **38** and suction pump **36** individually or in combination. While hydraulic power systems are used in the preferred embodiment of the present invention, it is to be understood that other types of power systems, including electric motors or internal combustion engines, may be used to power the apparatus.

The main control system **30**, located in a cab in the central area of the trailer **10**, controls the auger speeds, suction pump speed, and control valves, as well as the rotary drive units **78** connected to the impellers **74** in the blending tubs **12**, **14**. A suitable computer may be used to control the operation of the system so that a desired slurry density is achieved. While the main control system **30** is located on deck **22**, it may be remotely located.

FIGS. **3** and **6** illustrate the manifold systems that connect the blending tubs **12**, **14**.

The fluid intake manifold **34** includes a hydraulic suction pump **36**, hydraulic drive unit **38**, left intake bank **40**, right intake bank **48**, T-junction **56**, main intake pipe **58**, and a Y-junction **60**. The suction pump **36**, powered by the drive unit **38**, supplies fracturing fluid to the blending tubs **12**, **14** through the main intake pipe **58**, and includes a speed control for controlling the combined rate of fluid flow to the blending tubs **12**, **14**. The left and right intake banks **40**, **48** are positioned on both sides of the apparatus to allow convenient positioning of one or more sources of fracturing fluid. Water, diesel fuel, gelled solution, or other suitable solutions may be used for the fracturing fluid. Hose connectors **42** and shut off valves **44** are included with the left intake bank **40**. Hose connectors **50** and shut off valves **52** are included with the right intake bank **48**. The T-junction **56** connects the left intake bank **40** and right intake bank **48** with the pump **36** and the main intake pipe **58**. Bank valves **46**, **54** allow the left and right intake banks **40**, **48**, respectively, to be operated separately or in combination. The Y-junction **60** connects the main intake pipe **58** to equal length pipe sections **64**, **70**, which deliver the fracturing fluid to the blending tubs **12**, **14**, respectively. Pipe section **64** connects to tangential inlet **66** on blending tub **12** and pipe section **70** connects to tangential inlet **72** on blending tub **14**. Pipe section **64** includes control valve **62** and pipe section **70** includes control valve **68**. Control valves **62**, **68** allow the blending tubs **12**, **14** to be operated separately or in combination.

The blending tubs **12**, **14** may be cylindrically shaped, with a closed bottom surface and a partially open top surface. FIGS. **4** and **5** show the blending tub **12**. Blending tub **14** may be configured similar to blending tub **12**. As shown in FIGS. **4** and **5**, the blending tub **12** includes a horizontally rotating impeller **74**. A drive shaft **76** protrudes vertically upward through the top of the tub and connects to a hydraulic drive unit **78**. Particulate matter is fed by gravity through the distribution bin **24** and into an opening in the top surface of the blending tub **12**. Sand, glass beads, walnut shells, poly abrasive or other suitable materials may be used as the particulate matter. Fracturing fluid is introduced into the blending tub **12** by a tangential inlet **66** located in the upper portion of the blending tub **12**. A plenum space **86** is provided in the blending tub **12** below the rotating impeller **74**. As the fracturing fluid and particulate matter gravitate downward through the blending tub **12**, they are mixed into a slurry and exit through a tangential discharge outlet **88** located on the lower portion of the blending tub **12**.

The impeller **74** comprises an upper ring **80** and a lower disk **82** sharing a common axis of rotation defined by the drive shaft **76**. The impeller **74** may be positioned horizontally. The open area surrounded by the upper ring **80** allows the drive shaft **76** to connect to the lower disk **82**. The upper ring **80** and lower disk **82** are connected to each other by a plurality of blade me **84** mounted perpendicularly between the upper ring **80** and lower disk **82** at the periphery. The upper ring **80**, lower disk **82** and blade members **84** are constructed of hardened steel or other suitable material capable of withstanding the abrasive and erosive characteristics of the slurry. The diameter of the impeller **74** is smaller than the inner diameter of the tub and allows sufficient clearance for the fluid and particulate matter to pass. The impeller **74** is suspended by the drive shaft **76** approximately eight to ten inches above the bottom of the tub, thus creating the plenum space **86** at the bottom of the tub under the impeller **74**. It is believed that a buoyancy factor created within the plenum space **86** helps balance the individual tub pressures in the slurry discharge manifold **100**.

The slurry discharge manifold **100** carries the slurry from the blending tubs **12, 14**. Slurry exits the blending tub **12** from tangential outlet **88** and blending tub **14** from tangential outlet **94**. Tangential outlets **88, 94** are connected to equal length pipe sections **90** and **96**, respectively. Pipe section **90** includes control valve **92**, and pipe section **96** includes control valve **98**. Control valves **92, 98**, in combination with control valves **62, 68**, allow the blending tubs **12, 14** to be operated separately or in combination. The slurry discharge manifold **100** includes Y-junction **102**, main discharge pipe **104**, left discharge bank **112** and right discharge bank **118**. Y-junction **102** connects the pipe sections **90** and **96** to the main discharge pipe **104**. The main discharge pipe **104** is connected to a second Y-junction **106** and control valves **108 110**, where the slurry may be distributed between the left discharge bank **112** and right discharge bank **118**, respectively. Left discharge bank **112** includes hose connectors **116** controlled by shut off valves **114**. Right discharge bank **118** includes hose connectors **120** controlled by shut off valves **122**. The pressure from the blending tubs is sufficient to carry the slurry through the slurry discharge manifold **100**. A cross-over valve **124** connects the main intake pipe **58** and the main discharge pipe **104**. The cross-over valve **124** allows the tubs to be completely bypassed and delivers fracturing fluid directly to the left and right discharge banks **112, 118**.

It appears that the equal length pipe sections **90** and **96** are critical to producing the constant and balanced outlet pressure. This is apparently true in the manifolding together of any number of blending tubs. Thus, alternative embodiments of the present invention may incorporate numerous additional blending tubs. Additionally, the provision of the plenum **86** in the bottom area of the tub below the impeller **74** with the outlet pipe connected to the tub in this lower area also contributes to and enhances the balancing of the outlet pressure from each tub to provide the constant outlet pressure necessary for downhole fracturing operations.

The base structure may incorporate a chassis which can be mounted or built on a semi-trailer, skid frame, vessel, or other structure. The complete apparatus may be constructed for operation in any type of environment where well servicing is required.

Operation

The operation of both blending tubs **12, 14** is performed as follows. A source of fracturing fluid is connected to one or more of the intake hose connectors **42, 50**. Upon startup of the deck engines **26**, the hydraulic pumps **28** are activated. The suction pump **36** is activated, and the fracturing fluid is drawn into the fluid intake manifold **34**. To balance the inlet pressure against the pressure of the tubs, the slurry is mixed in the blending tub **12** with the impeller rotating at approximately 600 rpm or greater and the inlet control valve **62** and outlet control valve **92** open. The conveyor augers **20** are activated, and particulate matter is transported from the hopper **16** to the distribution bin **24**. The particulate matter is then distributed to the blending tub **12**.

The slurry is passed through the slurry discharge manifold **100** and one or more of the discharge hose connectors **116, 120** to a connected downhole pumping apparatus. The second tub **14** is operated at approximately the speed of the first tub before being filled with fracturing fluid and introducing the particulate matter. Once the fracturing fluid and particulate matter begin mixing, the inlet and outlet control valves **68** and **98** are opened on the second blending tub. The outlet pressures of the blending tubs **12, 14** balance and equalize in the discharge manifold **100**, thus providing constant pressure to the downhole pump. The resulting constant outlet pressure from the tubs prevents the slurry from overflowing or exiting the tops of the blending tubs. The discharge pressure from the discharge manifold **100** is approximately **5** PSI greater than the pressure in the intake manifold **34**.

In the preferred embodiment of the invention, the slurry is mixed to a density of up to approximately 22 pounds of particulate matter per gallon of fracturing fluid. The discharge flow rate per blending tub is approximately 40 barrels per minute, with a combined flow rate of 80 barrels per minute for both blending tubs operated simultaneously. The discharge pressure is approximately 50–60 psi. Both blending tubs **12, 14** remain in operation without the use of throttle valves, and no leveling of the blending tubs is required.

An apparatus that balances the pressures of multiple blending tubs while maintaining a constant balanced output pressure has been illustrated and described in detail. It is to be understood that details of the present invention may be modified without departing from the spirit thereof.

What is claimed is:

1. A multiple tub blending apparatus for producing slurry for use in well servicing operations, said blending apparatus comprising:

(a) a plurality of blending tubs, each of said tubs having a fracturing fluid inlet means and a particulate matter inlet means, an outlet means, and a mixing means for producing a slurry of fracturing fluid and particulate matter, said fluid and matter inlet means being connected to a source of fracturing fluid and a source of particulate matter, respectively;

(b) a single discharge manifolding means for combining the discharges from the multiple blending tubs, balancing simultaneously the outlet pressures of said blending tubs and delivering a slurry of fracturing fluid and particulate matter from said blending tubs at a constant outlet pressure, said discharge manifolding means further including a discharge manifold pipe and individual pipe sections having approximately equal length for connecting the discharge manifold pipe to the outlet means of each of said blending tubs, said equal length pipe sections have approximately equal pressure drop which produces a substantially balanced and constant outlet pressure in said blending tub outlet means; and

(c) connector means for connecting said discharge manifold pipe of the discharge manifolding means to a downhole pump apparatus, wherein the constant outlet pressure of the discharge manifolding means supports and stabilizes the inlet pressure of the downhole pump during well servicing operations.

2. The blending apparatus as defined in claim **1**, further including an intake manifold means for delivering fracturing fluid to said blending tubs, said intake manifold means being connected to said source of fracturing fluid and said inlet means of said blending tubs.

3. The blending apparatus as defined in claim **1**, wherein said blending tub includes a plenum space substantiality beneath said mixing means.

4. The blending apparatus as defined in claim **3**, wherein said plenum space is proximate to the outlet means of said blending tub.

5. The blending apparatus as defined in claim **1**, wherein said mixing means is an impeller which rotates about a vertical axis and is suspended from above.

6. The blending apparatus as defined in claim **1**, wherein each of said blending tubs includes a control valve on each of said inlet means and said outlet means.

7. The blending apparatus as defined in claim **1**, further comprising a loading means for depositing particulate matter in one or more of said blending tubs.

8. The blending apparatus as defined in claim **7**, wherein the loading means for depositing particular matter in one or more of said blending tubs is an auger type conveyor means.

9. The blending apparatus as defined in claim **1**, wherein said apparatus is mounted on a vehicle.

10. The blending apparatus as defined in claim **1**, further comprising a control means for controllably operating the charging and discharging of fracturing fluid and particulate matter in one or more of the blending tubs.

11. The blending apparatus as defined in claim **1**, wherein said mixing means includes an impeller which rotates about a vertical axis and is suspended from above, and said blending tub includes a plenum space substantially beneath said impeller.

12. The blending apparatus as defined in claim **1**, wherein said mixing means is an impeller which rotates about a vertical axis and is suspended from above, and wherein said blending tub includes a plenum space substantially beneath said impeller and proximate to the outlet means of said blending tub.

13. The blending apparatus as defined in claim **1**, further including an intake manifolding means for delivering fracturing fluid to said blending tubs, said intake manifolding means being connected between said source of fracturing fluid and said inlet means of said blending tubs, and the inlet means on each blending tub is connected to said inlet manifolding means by pipe sections having approximately the same length to provide substantially equal inlet pressures in said blending tubs during well servicing operations.

14. A multiple blending tub apparatus for providing a slurry of fracturing fluid and particulate matter at a high flow rate for use in well servicing operations, said blending apparatus comprising a single discharge manifolding means for combining the discharges from multiple blending tubs, simultaneously balancing the outlet pressures of said blending tubs and delivering a slurry of fracturing fluid and particulate matter from said blending tubs at a constant outlet pressure, said apparatus including a plurality of blending tubs each having a centrifugal impeller spaced above the bottom of the tub forming a plenum space and a tangential outlet means adjacent to the plenum space for the discharge from each tub.

15. The blending apparatus as defined in claim **14**, further including separate pipe sections for connecting said blending tubs to said manifolding means, each of said pipe sections having approximately the same length to provide substantially equal pressures in said blending tubs during well servicing operations.

16. The blending apparatus as defined in claim **14**, further including an intake manifold means connected to a source of fracturing fluid, said intake manifold means delivers said fracturing fluid to said blending tubs.

17. A dual tub blending apparatus for use in well servicing operations, said blending apparatus comprising:

a) a pair of blending tubs, each of said tubs having a particulate matter inlet means, a fluid inlet means, a slurry outlet means, and a mixing means, the particulate matter inlet means including a distribution bin for storing the particulate matter and feeding the particulate matter to the individual blending tubs as needed, said bin being filled by a loading means which maintains an adequate supply of particulate matter in said bin;

b) said fluid inlet means on each tub being connected by pipe sections having approximately the same length to an inlet manifold pipe which is connected to a source of fracturing fluid which is used in the well servicing operations;

c) said slurry outlet means including a pair of individual pipe sections having approximately the same length connected to a slurry discharge manifold pipe for combining the discharges from the pair of blending tubs, balancing the outlet pressures of said blending tubs and delivering a slurry of fracturing fluid and particulate matter from said blending tubs at a constant outlet pressure to said discharge manifold pipe;

d) said blending tubs each having an impeller which rotates about a vertical axis and is suspended from above leaving an open plenum space below said impeller, said slurry outlet means for each tub being attached to the tub in the general area adjacent to said plenum space; and

e) connector means for connecting said slurry discharge manifold pipe to an inlet of a downhole pump apparatus, wherein the slurry constant outlet pressure from the discharge manifold pipe supports and stabilizes the inlet pressure of the downhole pump during well servicing operations.

18. In a multiple blending tub apparatus for use in well servicing operations, each of said blending tubs comprising:

a) a cylindrical tub having a side wall, an enclosed bottom and a partially open top;

b) a particulate matter inlet means provided through said top;

c) a fluid inlet means positioned in the side wall of said tub;

d) a slurry outlet means positioned in the side wall and below the fluid inlet means;

e) said tub having a centrally positioned impeller which rotates about a vertical axis and is suspended from above leaving an open plenum space between said impeller and the bottom of the tub, said impeller being driven by a suitable drive means; and

f) the particulate matter is introduced into the tub through the top of the tub and into the impeller, wherein the particulate matter is mixed with a fluid entering the tub through the fluid inlet means producing a slurry of fluid and particulate matter which descends into the open plenum space and is discharged through the slurry outlet means which is adjacent the plenum space, whereby the outlet flow of the slurry is stabilized and balanced by said open plenum space.

* * * * *

United States Patent [19]

Davis et al.

[11] **Patent Number: 4,854,714**

[45] **Date of Patent: Aug. 8, 1989**

[54] **BLENDER VEHICLE APPARATUS**

[75] Inventors: **Gail F. Davis; Robert L. Baker; Dale E. Bragg; Calvin L. Stegemoeller**, all of Duncan, Okla.

[73] Assignee: **Halliburton Company**, Duncan, Okla.

[21] Appl. No.: **199,961**

[22] Filed: **May 27, 1988**

[51] **Int. Cl.**[4] **B01F 15/02;** B01F 7/18; B28C 5/16; B28C 7/12

[52] **U.S. Cl.** **366/132;** 366/17; 366/27; 366/64; 366/136; 366/153; 366/183; 366/191; 366/319

[58] **Field of Search** .... 366/1, 2, 6, 7, 8, 16, 366/17, 18, 19, 20, 21, 27, 28, 29, 34, 40, 42, 43, 64, 131, 132, 136, 137, 182, 183, 197, 30, 191, 192, 194, 265, 279, 319, 329, 150, 154, 155, 167, 168, 153; 414/545, 556, 546; 175/206, 219, 213, 217, 207; 280/5 R, 5 C, 5 D, 5 E, 32.5; 410/68, 81; 108/44, 51.1

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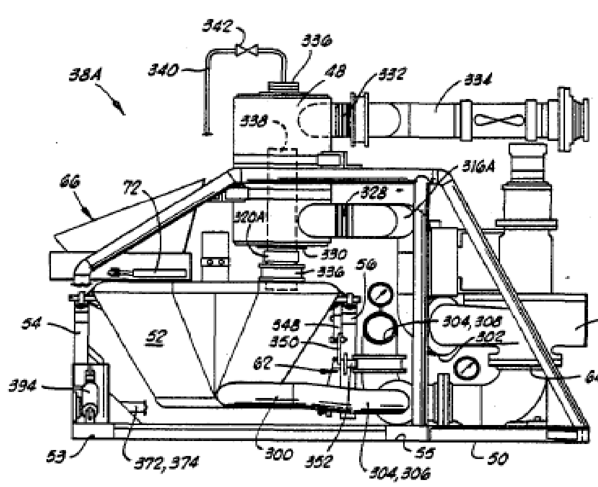
Exhibit B—Waltco hydraulic tailgate lifts brochure.
Exhibit C—Unnamed brochure.
Exhibit D—"Champ Tow-A-Lift" brochure of Champ Corporation of El Monte, Calif.
Exhibit E—Photograph labeled "Halliburton Drop--Tub Blender".
Exhibit F—Brochure on Agri-Tote system manufactured by Hoover Universal.
Exhibit G—Brochure of TransStore system manufactured by Custom Metalcraft.
Exhibit H—Photograph labeled "LGC Tank Mounting".
Exhibit I—Halliburton Services Sales and Service Catalog No. 43, p. 2504.

Primary Examiner—Harvey C. Hornsby
Assistant Examiner—Scott J. Haugland
Attorney, Agent, or Firm—James R. Duzan; Lucian W. Beavers

[57] **ABSTRACT**

A blender vehicle apparatus includes a vehicle having a vehicle frame. An internal combustion engine driven hydraulic power package is mounted on the vehicle frame. A plurality of liquid additive storage tanks are mounted on the frame adjacent the power package. An operator's work platform, including a control station, is mounted on the vehicle frame adjacent the storage tanks on a side thereof opposite the power package. A hydraulically powered blender assembly is also included, and a hydraulically powered lifting apparatus is mounted on the vehicle frame for moving the blender assembly between a lowered position and a raised position. The raised position of the blender assembly is located above the vehicle frame and adjacent the work platform on a side thereof opposite the storage tanks.

11 Claims, 14 Drawing Sheets



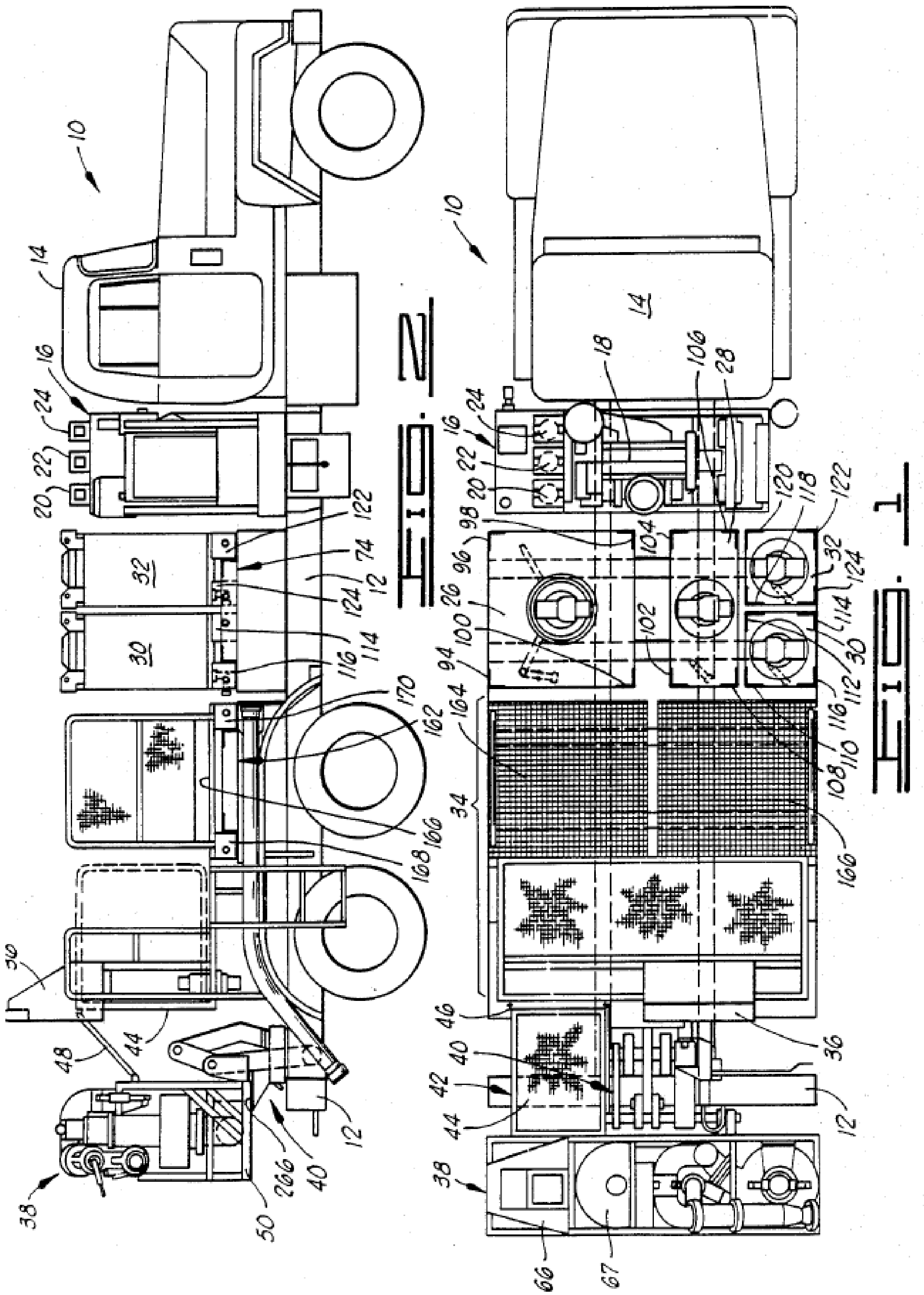


FIG. 2

FIG. 1

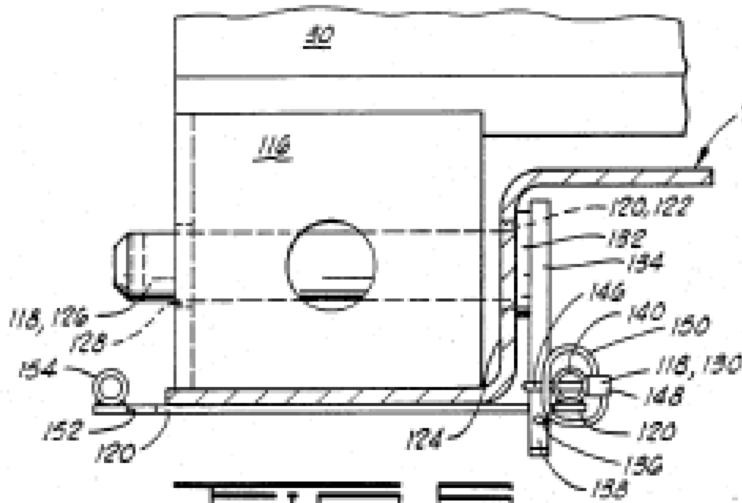


FIG. 6

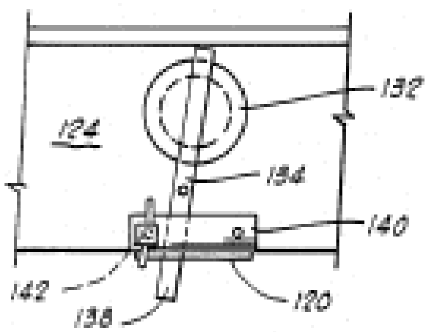


FIG. 7

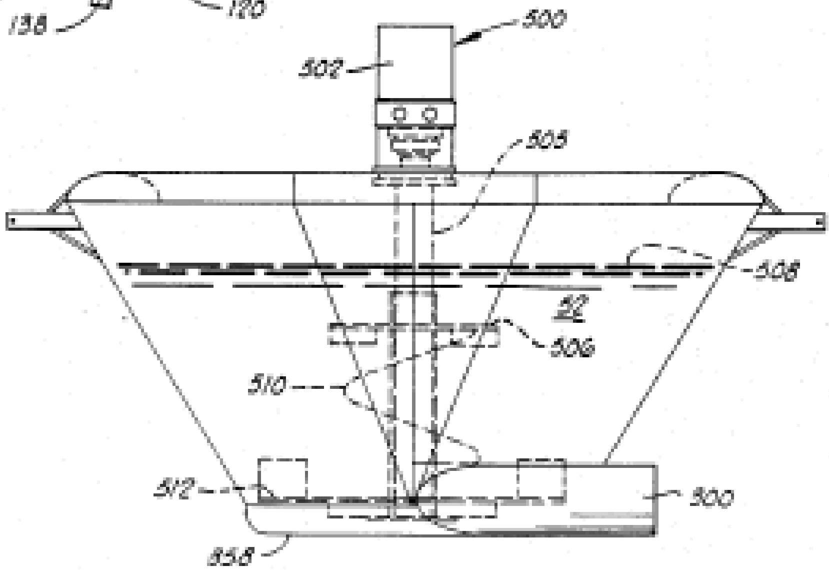


FIG. 18

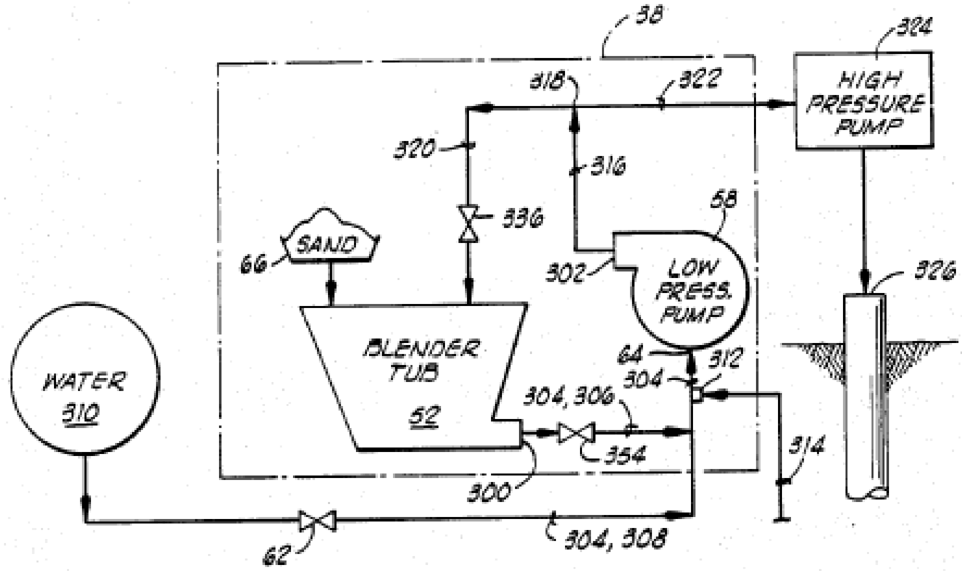

38
324
HIGH PRESSURE PUMP
318
322
320
316
336
58
SAND
66
302
LOW PRESS. PUMP
326
BLENDER TUB
52
64
312
WATER
310
304
304, 306
314
354
300
62
304, 308

FIG. 12

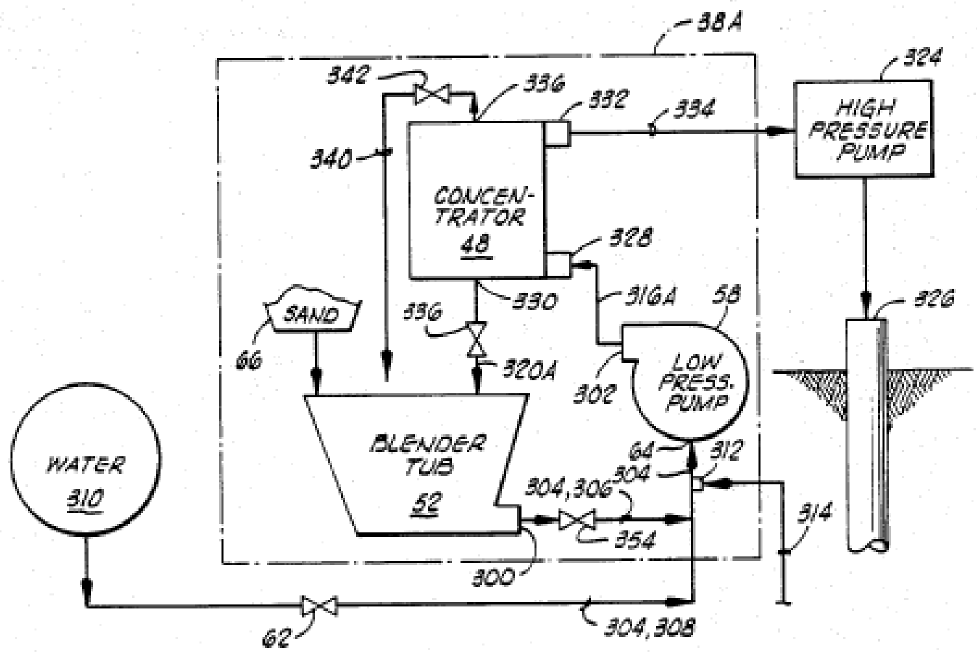

38A
324
342
336
332
334
HIGH PRESSURE PUMP
340
CONCEN-TRATOR
48
328
SAND
336
330
316A
58
326
66
320A
302
LOW PRESS. PUMP
BLENDER TUB
52
WATER
310
64
312
304
304, 306
314
354
300
62
304, 308

FIG. 13

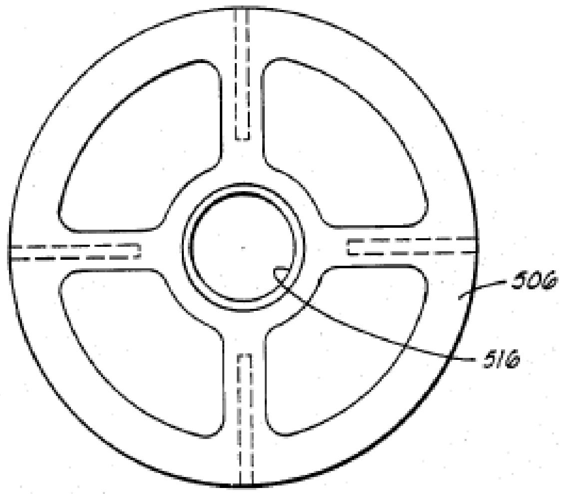


FIG. 19

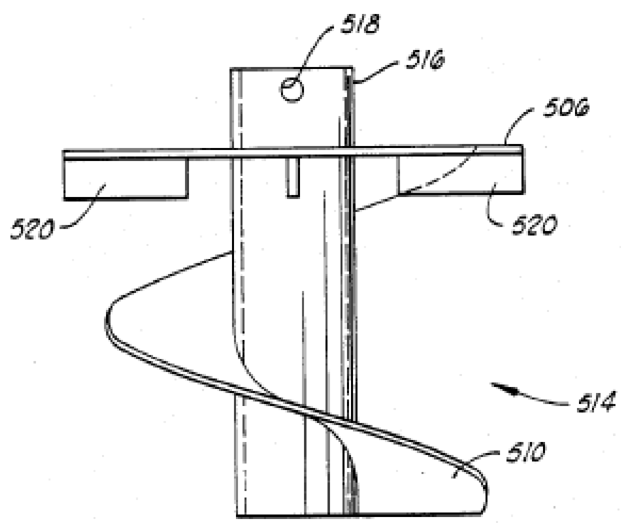


FIG. 20

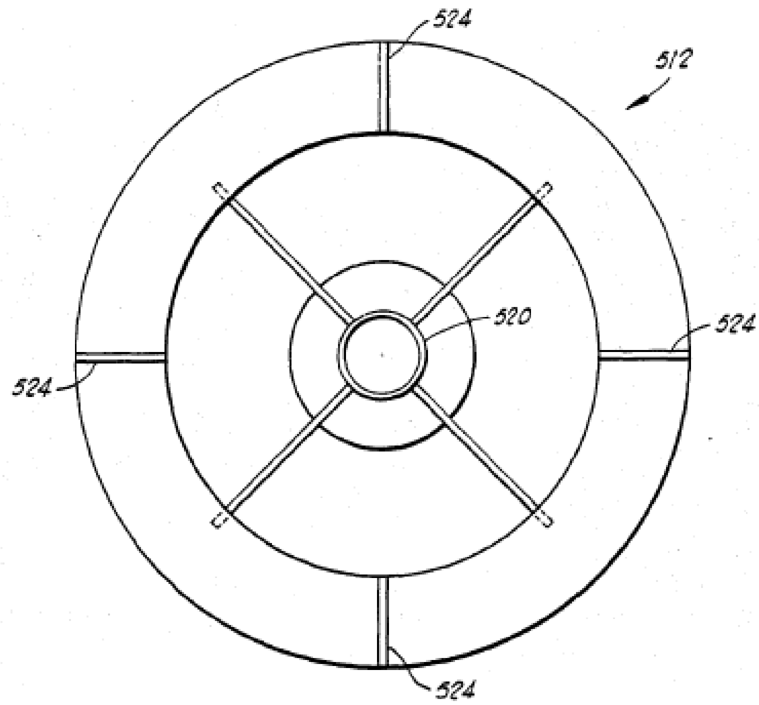


FIG. 21

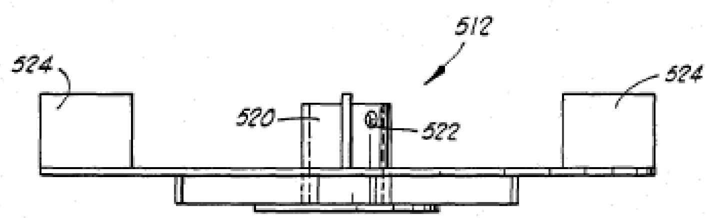


FIG. 22

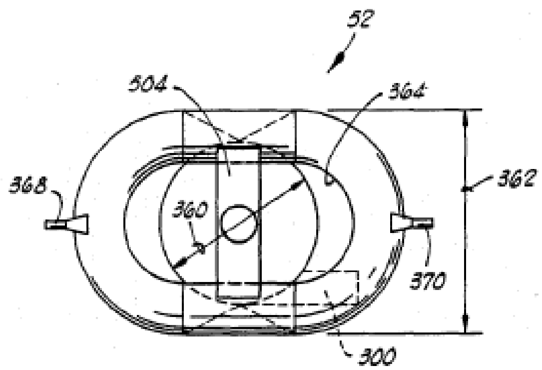


FIG. 23

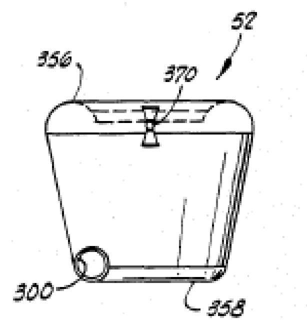


FIG. 25

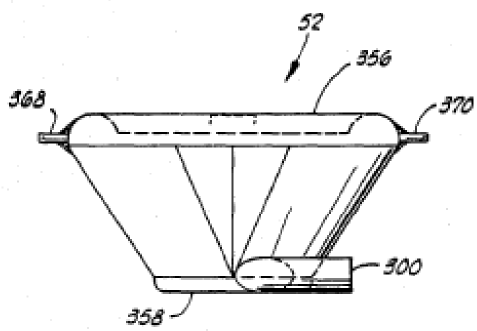


FIG. 24

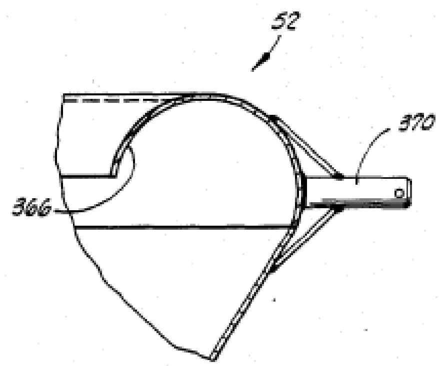


FIG. 26

BLENDER VEHICLE APPARATUS

BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention relates generally to blender apparatus, and particularly to a blender apparatus mounted upon a movable vehicle.

2. Description Of The Prior Art

Many activities conducted in connection with the servicing of oil wells involve the blending of one or more solid particulate materials with a liquid which is to be pumped down into a well.

Most such equipment is designed for relatively large jobs requiring the production of up to as much as 100 barrels per minute (BPM) of blended fluid, and utilize at least two pumps, one to deliver base fluid to the blender and another to pump the blended fluid away from the blender. Typical prior art blenders also often require more than one human operator.

A relatively recent development by the assignee of the present invention is the constant level additive mixing system disclosed in U.S. Pat. No. 4,490,047 to Stegemoeller et al. The Stegemoeller system utilizes a single pump to both draw clean fluid from a fluid supply and draw blended fluid from a relatively small capacity blender. A first portion of the fluid is then recirculated back to the blender, while a second portion is discharged to high pressure pumps which pump the blended fluid down into a well.

The Stegemoeller et al. '047 system also introduces the concept of an automatic leveling device for controlling the level of the fluid in the blender tub.

The particular system disclosed in Stegemoeller et al. was designed to be hung on the side of a vehicle such as an acidizing truck, so that the blender could be utilized to mix various additives with the acids which were to be pumped downhole.

The tub assembly shown in the Stegemoeller et al. '047 patent has also been used by the assignee of the present invention on the rear of a fracturing truck. In that assembly, the tub was fixed to the rear of the truck and did not move other than to rotate upon its torsion bar.

SUMMARY OF THE INVENTION

The present invention provides an improved version of the constant level additive mixing system of Stegemoeller et al., and the particular embodiment claimed herein provides a self-contained vehicle carrying the improved blender along with a hydraulic power package, a plurality of liquid additive storage tanks, an operator's work platform, and a hydraulically powered lifting means for moving the blender assembly between a lowered ground level position and a raised vehicle frame level position.

This provides a relatively inexpensive multi-purpose blender system which can be easily moved to any desired point of usage.

Numerous objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the following disclosure when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view of a truck-mounted blender system with associated power source, liquid additive storage, work station, and lifting apparatus.

FIG. **2** is an elevation view of the apparatus of FIG. **1**.

FIG. **3** is a plan view of the mounting rack for the liquid additive tanks.

FIG. **4** is a side elevation view of the mounting rack of FIG. **3**.

FIG. **5** is an end elevation view of the mounting rack of FIG. **3**.

FIG. **6** is an enlarged sectioned view taken along line **6—6** of FIG. **3** showing the details of the connecting pin and retainer pin as assembled with the mounting rack and a container.

FIG. **7** is a right end view of the structure of FIG. **6**, with the container not shown in this view.

FIG. **8** is a plan view of the lifting apparatus mounted on a truck bed showing the apparatus in the DOWN position.

FIG. **9** is a side elevation view of the lifting apparatus of FIG. **8** showing the apparatus in the UP position.

FIG. **10** is a side elevation view similar to FIG. **9** but showing the lifting apparatus in the DOWN position.

FIG. **11** is a plan view similar to FIG. **8** showing the latch assembly for locking the lifting apparatus in its UP position.

FIG. **12** is a schematic flow diagram of the blender system.

FIG. **13** is a schematic flow diagram similar to FIG. **12**, showing the addition of a concentrator downstream of the low pressure pump.

FIG. **14** is a rear elevation view of the blender assembly of FIG. **1**, which has been modified by the addition of a concentrator downstream of the low pressure pump. The blender assembly of FIG. **14** utilizes a steel blender tub. It is noted that this rear elevation view is taken as it would be seen standing behind the rear of the truck **10** and looking toward the blender apparatus **38**.

FIG. **15** is a right end elevation view of the apparatus of FIG. **14**.

FIG. **16** is a plan view of the apparatus of FIG. **14**.

FIG. **17** is a left end elevation view of the apparatus of FIG. **14**.

FIG. **18** is an enlarged view of the blender tub showing in dashed lines the location of a mechanical agitator located therein.

FIG. **19** is a plan view of the top rotating agitator means of the mechanical agitator.

FIG. **20** is an elevation view of the top rotating agitator means of FIG. **19**.

FIG. **21** is a plan view of a bottom rotating agitator means of the mechanical agitator.

FIG. **22** is an elevation view of the bottom rotating agitator means of FIG. **21**.

FIG. **23** is a plan view of a steel blender tub.

FIG. **24** is a rear elevation view of a steel blender tub.

FIG. **25** is a right end elevation view of the blender tub. of FIG. **24**.

FIG. **26** is an enlarged sectioned view of the upper perimeter of the blender tub of FIG. **24**.

FIG. **27** is a plan view of a non-metallic blender tub liner of the type utilized with a tub support framework.

FIG. **28** is a rear elevation view of the tub liner of FIG. **27**.

FIG. 29 is a right end elevation view of the tub liner of FIG. 28.

FIG. 30 is a plan view of an alternative embodiment of the blender assembly, wherein the tub and its self-leveling control apparatus are contained on a skid which does not contain a pump. Connections are provided for connecting the blender tub of FIG. 30 to an external pump. The blender tub of FIG. 30 utilizes a non-metallic liner contained within a supporting framework.

FIG. 31 is a rear elevation view of the apparatus of FIG. 30.

FIG. 32 is a left end elevation view of the apparatus of FIG. 31.

FIG. 33 is a right end elevation view of the apparatus of FIG. 31.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

General Description Of The Layout Of The Vehicle

Turning now to the drawings, and particularly to FIGS. 1 and 2, a blender vehicle apparatus is thereshown and generally designated by the numeral **10**. In the particular embodiment shown, the vehicle **10** is a motor truck having a vehicle frame **12** with a driver's cab **14** mounted thereon.

Behind the cab **14** there is located an internal combustion engine driven hydraulic power package generally designated by the numeral **16**. The power package **16** includes an internal combustion engine **18** which drives three hydraulic power pumps **20**, **22** and **24** which provide hydraulic power fluid to the various other systems located upon the frame **12** of the vehicle **10**.

The various systems mounted on the vehicle **10** have a power requirement which can be supplied by only two of the three hydraulic power pumps **20**, **22** and **24**, thus providing a safety feature in that if one of the pumps **20**, **22** and **24** fails, there will be sufficient hydraulic power provided by the two remaining pumps to complete a well service job which is under way.

Adjacent and to the rear of the power package **16**, a plurality of liquid additive storage tanks **26**, **28**, **30** and **32** are mounted upon the frame **12**.

An operator's work platform **34**, which includes a control station **36** is mounted on the vehicle frame **12** to the rear of and adjacent the storage tanks **26–32**.

To the rear of the work platform **34** there is located a hydraulically powered blender assembly generally designated by the numeral **38**.

A hydraulically powered lifting means generally designated by the numeral **40**, is mounted on the vehicle frame **12** for moving the blender assembly **38** between a lowered or DOWN position as illustrated in FIGS. 1, 8 and 10 and a raised position as illustrated in FIGS. 2 and 9. The raised position of blender assembly **38**, as seen in FIGS. 2 and 9, has the blender assembly **38** located above the vehicle frame **12** and relatively closely adjacent the work platform **34** on the side thereof opposite the storage tanks **26–32**.

The lifting means **40** is further characterized in that when the blender assembly **38** is in its raised position as shown in FIG. 2, the blender assembly **38** is located at least in part directly above the vehicle frame **12**. When the lifting means **40** moves the blender assembly **38** from its raised position to its lowered position as seen in FIGS. 1 and 10, the blender assembly **38** is moved in a generally horizontal direction rearward away from the work platform **34** and then is moved downward to an elevation as seen in FIG. 10 which is lower than the vehicle frame **12**.

The importance of this is that regulations for loads pulled on the public highways prevent the extension of a load more than two feet behind the end of the vehicle frame. The construction of lifting means **40** allows compliance with such regulations while at the same time providing a means for easily moving the load to the rear of the vehicle frame **12** and then downward to a ground level position.

A fold-up walkway means generally designated by the numeral **42** includes a walkway **44** having one end thereof pivotally mounted at **46** adjacent the work platform **34**. The walkway **44** extends generally horizontally from the work platform **34** to the blender assembly **38** when the blender assembly **38** is in its lowered position as is best in FIG. 1.

The fold-up walkway means **42** includes a walkway linkage **47**, best seen in FIG. 2, constructed to swing the walkway **44** up towards the work platform **34** when the blender assembly **38** is moved from its said lowered position to its said raised position as illustrated in FIG. 2.

The details of the blender assembly **38** are best shown in FIGS. 14–17. It is noted that the blender assembly shown in FIGS. 14–18 is slightly modified as compared to that shown in FIGS. 1 and 2, in that a concentrator means **48** has been added to the blender assembly. To designate this modification, the blender assembly of FIGS. 14–17 is designated by the numeral **38A**. Aside from the differences associated with the addition of the concentrator means **48**, however, the blender assembly **38A** is generally the same as and is representative of the blender assembly **38** of FIGS. 1 and 2. In the following description any reference to blender assembly **38** or blender assembly **38A** may be taken as referring to either unless the context of the reference deals with the concentrator **48** or associated apparatus which are found only on the embodiment **38A**.

Turning attention now to the general arrangement of the apparatus contained in the blender assembly **38**, with particular reference to FIG. 14, the blender assembly includes a blender assembly base **50**. A blender tub **52** is supported from the base **50** by first and second spaced parallel support arms **54** and **56**. In a manner further described below, the support arms **54** and **56** are pivotally connected to the base **50**, and the blender tub **52** is pivotally suspended from the support arms **54** and **56**.

The blender assembly base **50** may also be generally described as a blender pallet base **50** having a pair of fork openings **53** and **55** defined therein. The lifting means **40** includes a load fork **57** having a pair of tines **59** and **61** which are received in the fork openings **53** and **55** of pallet base **50**.

The blender assembly **38** further includes one and only one blender pump means **58**, supported from the base **50**, for drawing base fluid or "clean" fluid through a fluid supply conduit **304**, **306** from a fluid supply (not shown) and for drawing blended fluid from the blender tub **52**. The pump means **58** recirculates a portion of the combined base fluid and blended fluid back to the blender tub **52**, and discharges another portion of the combined base fluid and blended fluid away from the blender assembly **38**. The base fluid is often referred to as "clean" fluid, but it should be noted that the base fluid is often clean only in the sense that it has not yet

Appendix C: Other Company Blender Solutions

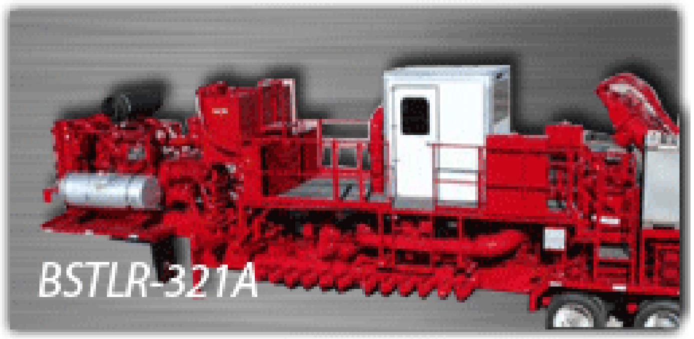
National Oilwell Varco

MT-1060 Blender equipped with eight (8) precision chemical metering systems

Features:

- Trailer Mounted
- Max rate operating configurations froms 60 BPM to 100 BPM
- Up to eight chemical systems (dry or liquid) acailable with variety of styles and delivery rates available
- Choice of twin or triple proppant augers in several available configurations and sizes
- Fixed or swing out auger systems

Serva Group



BSTLR-321A Blender

Features:

- Trailer Mounted
- Fluid Rate – 120 bpm
- Two 12” and one 6” auger hydraulically driven
- Four liquid additive pumps, hydraulically driven

Jereh

Jereh HST360 Blender

Features:

- Trailer Mounted
- Two 12” and one 8” screw conveyors
- Max Sand convey rate: 12,713 ft^3/hr
- Max discharge flowrate: 125 bbl/min
- Max sand density: 150 lb/ft^3

Tarcom

Tarcom Blender II

Features:

- Single man operated grom climate controlled cabin
- Powered by 460 hp truck engine
- Data Acquisition System able to record and display up to 200 parameters in real time from different rates, temperatures, and pressures.

NRG Manufacturing

1320 Blender

Features:

- Two 12” augers and one 6” auger.
- 12” augers deliver up to 9500 lb/min
- 6” augers deliver 4000 lb/min
- Includes automatic grease dispensing system to provide lubricant to the lower bearings

Fracturing Blenders

Stewart & Stevenson's fracturing blenders provide industry-leading job performance and reliability. Our blenders allow operators to mix complex fracturing slurries with varying densities for the most demanding treatments.

Stewart & Stevenson's AccuFrac System provides automated density and chemical controls in a user-friendly interface from the unit or data van. The unique concentric mixing chamber provides accurate and homogenous proppant mixing at both low and high rates without air entrainment. Highly efficient closed loop hydraulic systems provide faster response than open loop systems, while consuming less power and producing less waste heat for longer component life and reduced maintenance requirements.

MS-60 Skid mounted blender.

MT-132 Trailer mounted fracturing blender.

MC-60 Bodyload fracturing blender for extreme cold weather operations.

MT-102 Trailer mounted fracturing blender.

MC-60 Bodyload fracturing blender with closed chamber mixing system.

MT-132 Trailer mounted fracturing blender.

STEWART & STEVENSON FRACTURING BLENDERS

MODEL	MT-132 Trailer Mounted Blender	MT-102 Trailer Mounted Blender	MC-100 Bodyload Blender	MC-60 Bodyload Blender	MS-60 Skid Mounted Blender	MS-30 Skid Mounted Blender
Maximum Discharge Rate	130+ bbl/min	100 bbl/min	100 bbl/min	60 bbl/min (75 bbl/min optional)	60 bbl/min	30 bbl/min
Maximum Discharge Density	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal	21 lb/gal
Maximum Proppant Input Rate	21,250 lb/min (optional higher rates available)	21,250 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	16,000 lb/min (optional higher rates available)	6000 lb/min (optional higher rates available)
Carrier Type	Stewart & Stevenson trailer	Stewart & Stevenson trailer	Kenworth, Mercedes Benz or other truck chassis	Kenworth, Mercedes Benz or other truck chassis	Oilfield Skid	Oilfield Skid
Size: L × W × H	48'0" × 8'6" × 13'6"	48'0" × 8'6" × 13'6"	38'8" × 8'6" × 13'2"	34'8" × 8'6" × 13'2"	24'8" × 8'6" × 12'0"	19'6" × 8'6" × 8'0"
Mixing Chamber	Concentric tub with automatic level control	Concentric tub with automatic level control	Concentric tub with automatic level control	Pressurized mixing chamber or concentric tub	Pressurized mixing chamber or concentric tub	Hydrojet tub
Drive System*	(2) Deck engines	(2) Deck engines	(1) Truck engine and (1) deck engine	(1) Truck engine	(1) Deck engine	(1) Deck engine
Total Horsepower	1560 bhp	1560 bhp	1050 bhp	600 bhp	600 bhp	330 bhp
Number of Liquid Additive Systems	6 or more	6 or more	6 or more	6 or more	6 or more	6 or more
Number of Dry Additive Systems	Up to 2	Up to 2	Up to 2	Up to 2	Up to 2	Up to 2
Discharge Pump	14×12	14×12	14×12	Not Required	Not Required	5×6
Suction Pump	12×12	12×10	12×10	8×10	8×10	5×6
Automated Control System	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac	Stewart & Stevenson AccuFrac
Cold Weather Package	Optional	Optional	Optional	Optional	Optional	Optional

* Other manufacturers available

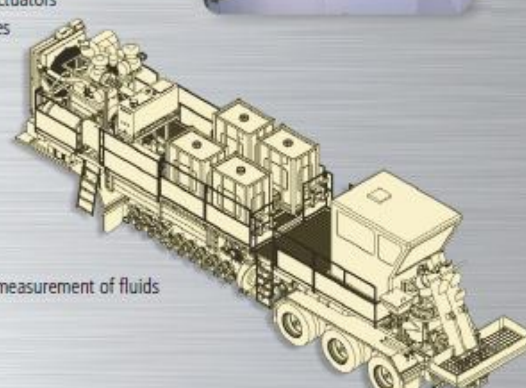
7

ENERFLOW INDUSTRIES INC.

Frac Blender

Features

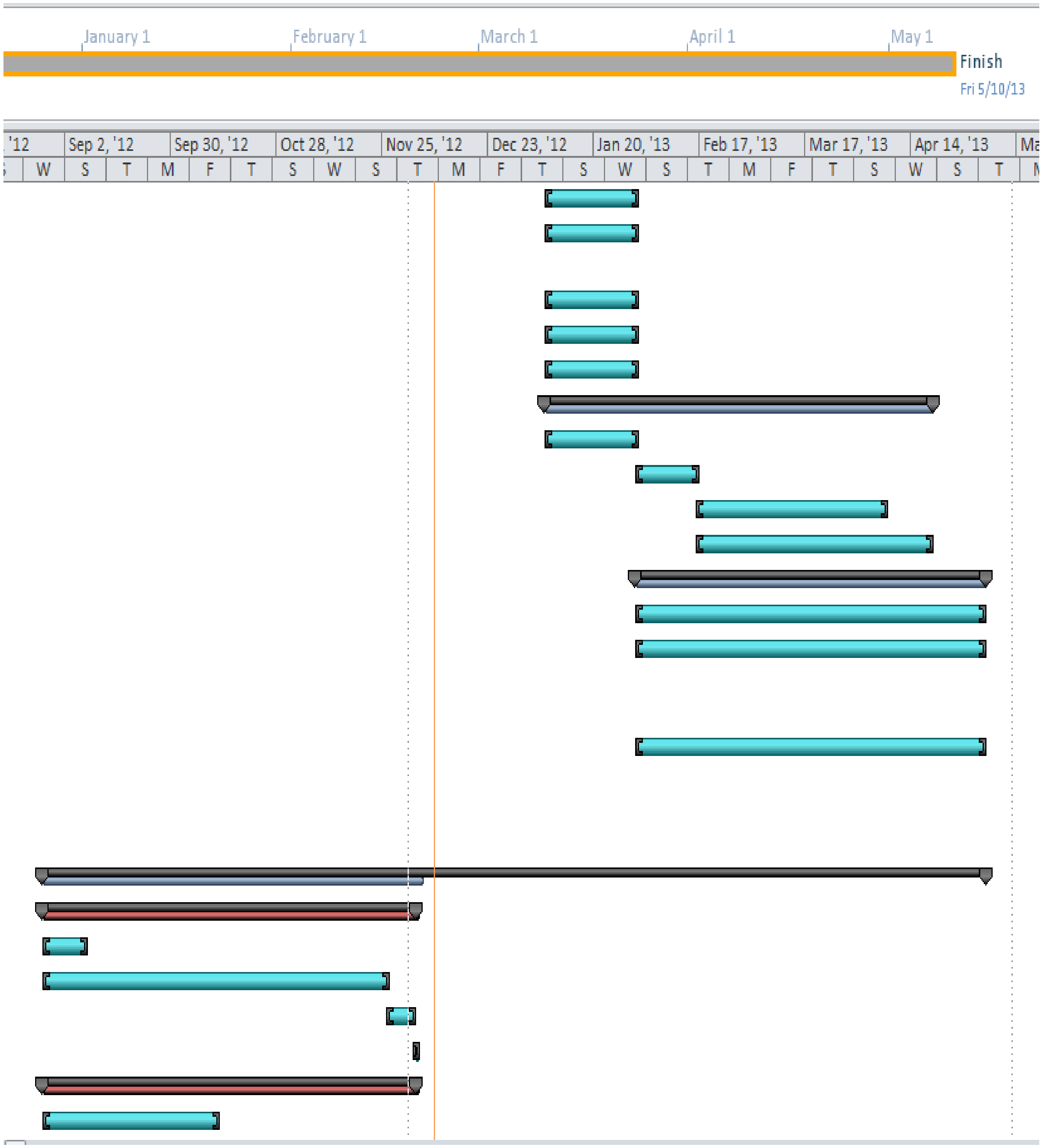
- Truck, Trailer or Skid Mounted
- Engine: Caterpillar, Cummins or Detroit Diesel (various Hp ratings)
- Twin augers
- Mixing tub
- Hydraulically driven mixing systems
- Liquid additive system
- Centrifugal suction pump
- Computer or manually controlled sand augers
- Suction and discharge manifolds on both sides of the unit for ease of rig up
- Suction and discharge manifold flow meters
- Pneumatic remote valve actuators
- Discharge and suction hoses
- Density gauge
- Swing augers
- Chemical transfer pump
- Viscometer
- Chemical totes
- Heated control cabin
- pH meter
- Dry additive systems
- ECAMS™ for control and measurement of fluids



Appendix D: Gantt Chart

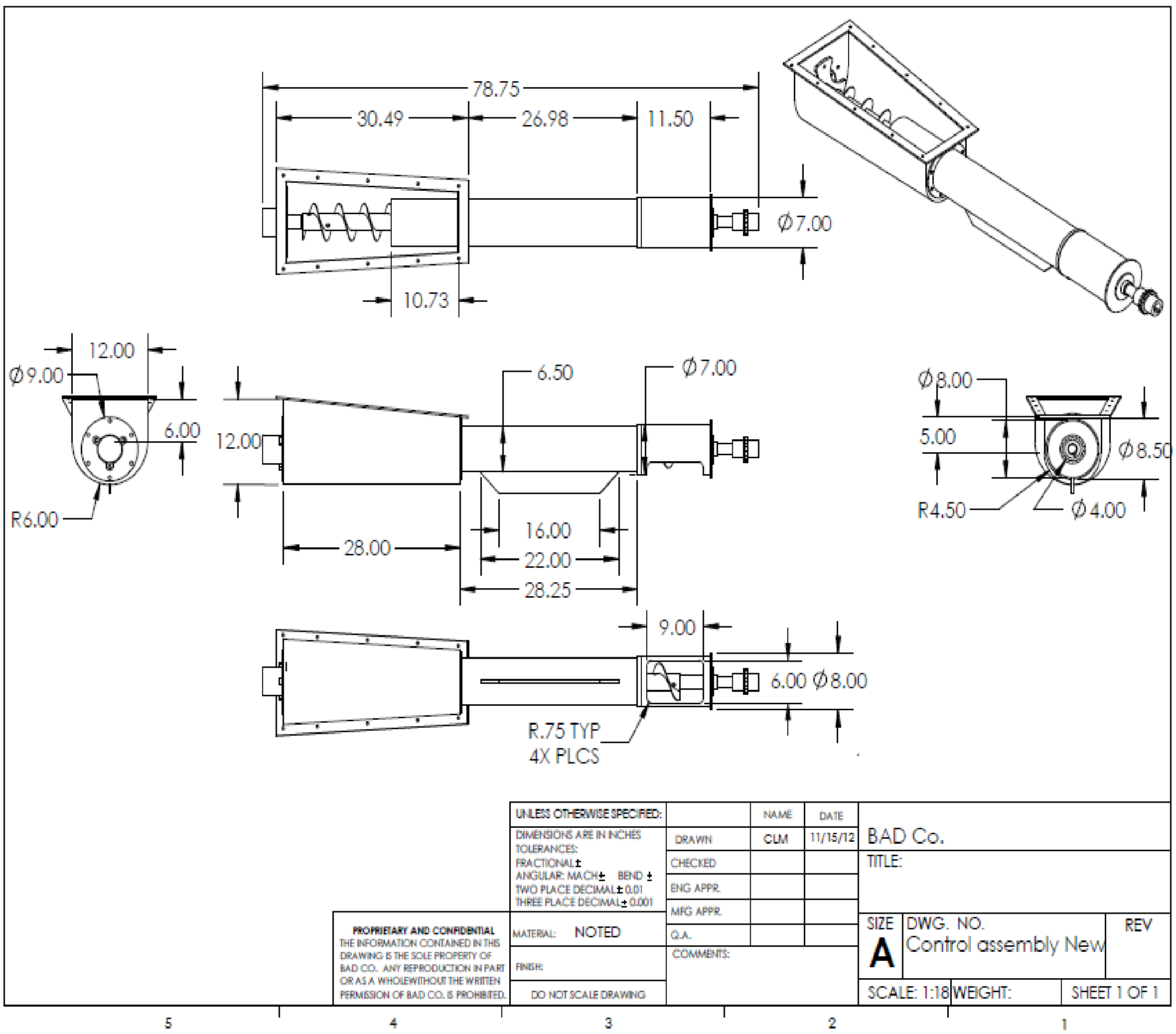
Task Name	Duration	Start	Finish
Optimize Auger Output	**185 days**	**Mon 8/27/12**	**Fri 5/10/13**
Produce Equation	**55 days**	**Mon 9/3/12**	**Fri 11/16/12**
Get test data from Halliburton	5 days	Mon 9/3/12	Fri 9/7/12
Analyze data in excel	10 days	Fri 9/7/12	Thu 9/20/12
Analyze data in TableCurve	14 days	Fri 9/21/12	Wed 10/10/12
Evaluate TableCurve equations	27 days	Thu 10/11/12	Fri 11/16/12
Choose best equation	1 day	Fri 11/16/12	Fri 11/16/12
Redesign equipment	**51 days**	**Mon 9/24/12**	**Sat 12/1/12**
Make SolidWorks drawing of 6" auger	15 days	Mon 9/24/12	Fri 10/12/12
Analyze current design shaft stresses	28 days	Mon 9/24/12	Wed 10/31/12
Generate redesign options	32 days	Fri 10/12/12	Mon 11/26/12
Choose best design options for prototypes	32 days	Fri 10/12/12	Mon 11/26/12
Prototype Testing	**85 days**	**Mon 1/7/13**	**Fri 5/3/13**
Acquire Equipment	**19 days**	**Mon 1/7/13**	**Thu 1/31/13**
Auger shafts	19 days	Mon 1/7/13	Thu 1/31/13
auger flighting	19 days	Mon 1/7/13	Thu 1/31/13
Auger bearings	19 days	Mon 1/7/13	Thu 1/31/13
auger housing	19 days	Mon 1/7/13	Thu 1/31/13
hoppers	19 days	Mon 1/7/13	Thu 1/31/13
variable speed drive and power source	19 days	Mon 1/7/13	Thu 1/31/13
proppant	19 days	Mon 1/7/13	Thu 1/31/13
Test stand	19 days	Mon 1/7/13	Thu 1/31/13
test site	19 days	Mon 1/7/13	Thu 1/31/13
Testing	**75 days**	**Mon 1/7/13**	**Fri 4/19/13**
Set up equipment	19 days	Mon 1/7/13	Thu 1/31/13
run control test	13 days	Thu 1/31/13	Sat 2/16/13
change variables	37 days	Sat 2/16/13	Sun 4/7/13
repeat test	46 days	Sat 2/16/13	Fri 4/19/13
Results	**67 days**	**Thu 1/31/13**	**Fri 5/3/13**
analyze test results	67 days	Thu 1/31/13	Fri 5/3/13
produce equation that describes new prototype output	67 days	Thu 1/31/13	Fri 5/3/13
compare prototype	67 days	Thu 1/31/13	Fri 5/3/13

equation with current design equation			
Report	**180 days**	**Mon 8/27/12**	**Fri 5/3/13**
Written report	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	10 days	Mon 8/27/12	Fri 9/7/12
write first draft	66 days	Mon 8/27/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize report	2 days	Mon 12/3/12	Tue 12/4/12
powerpoint	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	35 days	Mon 8/27/12	Fri 10/12/12
create first draft	32 days	Fri 10/12/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize presentation	2 days	Mon 12/3/12	Tue 12/4/12
Oral Presentation	**3 days**	**Mon 12/3/12**	**Wed 12/5/12**
practice presentation	1 day	Tue 12/4/12	Tue 12/4/12
present final report	1 day	Wed 12/5/12	Wed 12/5/12

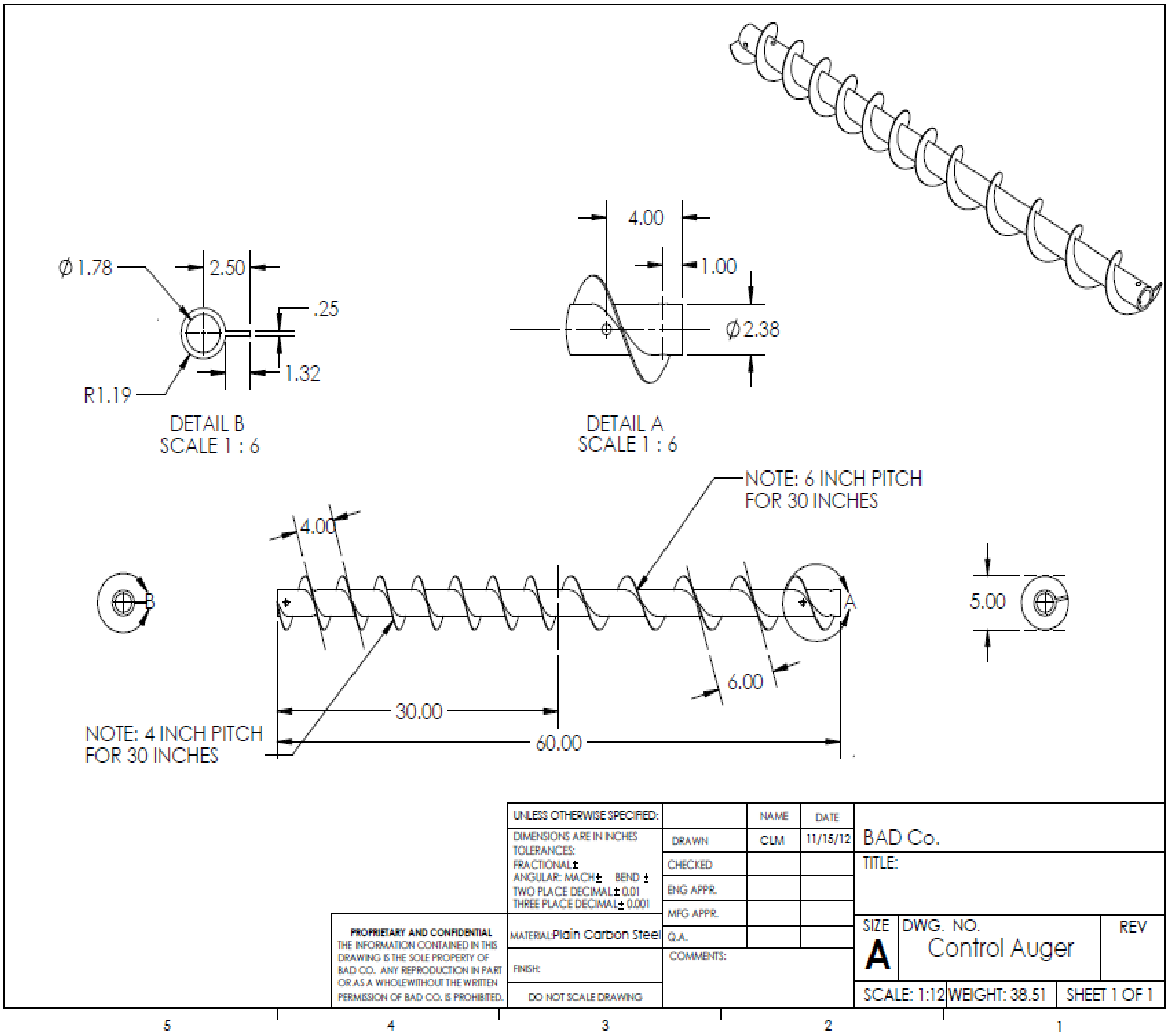

January 1
February 1
March 1
April 1
May 1
Finish
Fri 5/10/13
'12
Sep 2, '12
Sep 30, '12
Oct 28, '12
Nov 25, '12
Dec 23, '12
Jan 20, '13
Feb 17, '13
Mar 17, '13
Apr 14, '13
W S T M F T S W S T M F T S W S T M F T S W S T

Appendix E: Engineering Drawings

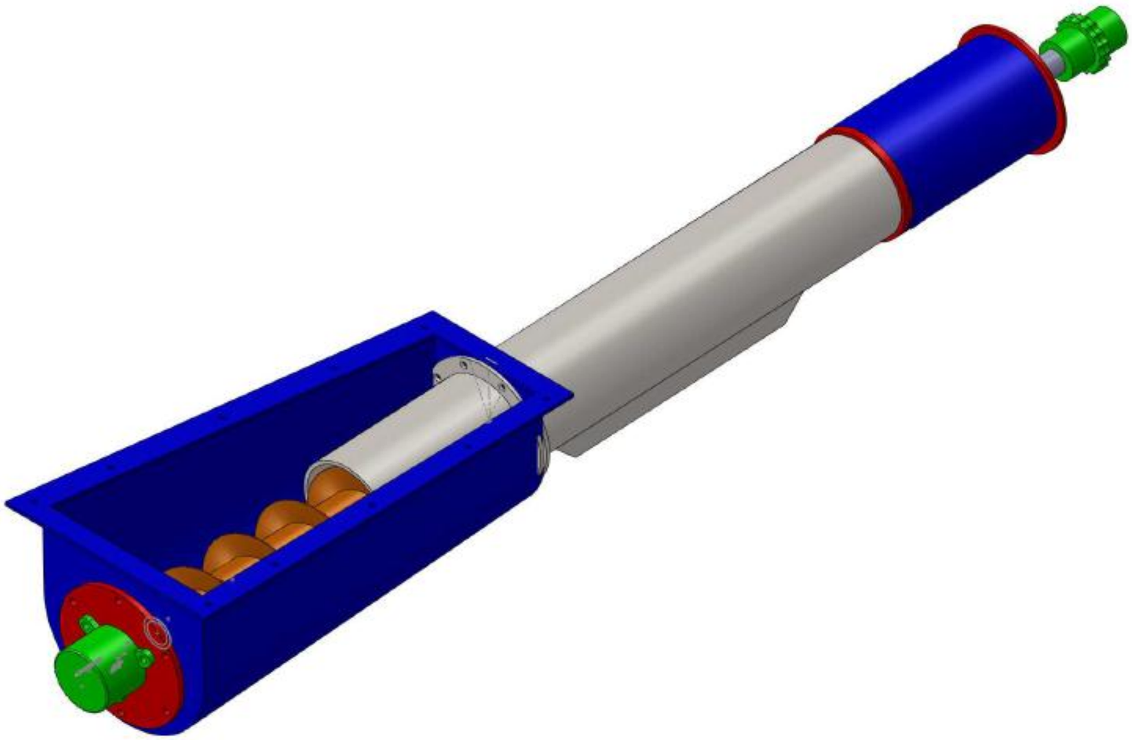
Housing Assembly:



Auger Assembly:



Control Assembly:



Appendix F: Work Breakdown Structure

1. Optimize Auger Output (100)
    - 1.1. Produce Equation (50)
        - 1.1.1. Obtain testing data in excel (5)
        - 1.1.2. Analyze excel data (5)
        - 1.1.3. Enter data into modeling software (5)
        - 1.1.4. Run simulation (10)
        - 1.1.5. Analyze simulation results (10)
        - 1.1.6. Produce and analyze equation (15)
    - 1.2. Redesign equipment (50)
        - 1.2.1. Analyze Current Auger Shaft Stresses (5)
        - 1.2.2. Decide which part needs redesigned (5)
        - 1.2.3. Create SOLID WORKS drawings of new designs (5)
    - 1.3. Acquire testing equipment and test site (5)
        - 1.3.1. Acquire auger (1)
        - 1.3.2. Acquire proppant from Halliburton (1)
        - 1.3.3. Acquire auger casing and stand (1)
        - 1.3.4. Acquire variable speed drive and power source (1)
        - 1.3.5. Acquire means of measuring output (1)
    - 1.4. Test prototype (15)
        - 1.4.1. Assemble prototype (5)
        - 1.4.2. Set up testing equipment (1)
        - 1.4.3. Run multiple tests (4)
            - 1.4.3.1. Measure proppant output vs RPM (2)
            - 1.4.3.2. Change speed of variable drive and repeat test (2)
        - 1.4.4. Alter prototype (if necessary) and repeat (5)
    - 1.5. Analyze test results (5)
    - 1.6. Create equation that describes output of new prototype (5)

Appendix G: Cost Of Equipment Needed

Auger Assembly:

- Flighting:
    - UltraFlyte: $60 (see below)
    - SuperFlyte: $120
        - Control
        - Exteneded pitch
        - Smaller shaft
- Screw Shaft (5 foot length)
    - 2” Schedule 80 having 2 3/8” OD: $30
    - 1 ¼” Schedule 80 having 1 ½” OD: $30
    - Fasteners: $20
- Screw Housing: $200
    - Housing Bracket: $75
    - Housing Fasteners: $35
    - Removable tube with flange: $30*
- Driveshaft Assebmly:
    - Roller Chain Couplers ($175 total after tax+shipping from McMaster Carr)
        - 1 ½” bore diameter hub (part # 6407K43): $24.33 (x3)
        - Roller Chain (part # 6407K53): $15.40
        - Cover Set (part # 6407K73) $69.85
    - Upper Shaft (1 ft length with key way):
        - 1 ½” OD_A and 1 ½” OD_B: $40*
        - 1.28” OD_A and 1 ½” OD_B: $40*
    - Bottom Shaft:
        - 1 ½” OD_A and 1 ½” OD_B: $40*
        - 1.28” OD_A and 1 ½” OD_B: $40*
- Bottom Bearing Assembly:
    - Support Plates: $50*
    - Ball Bearing (part # 60355K607): $50 (x2)
    - Housing: $30*
    - Fasteners: $20
- Top Housing:
    - Output chute: $40*
    - Discharge support: $50*
    - Fasteners: $20

- Test Stand: $150*
    - Fasteners: $20
- Hydraulic variable drive: $500*

Bins

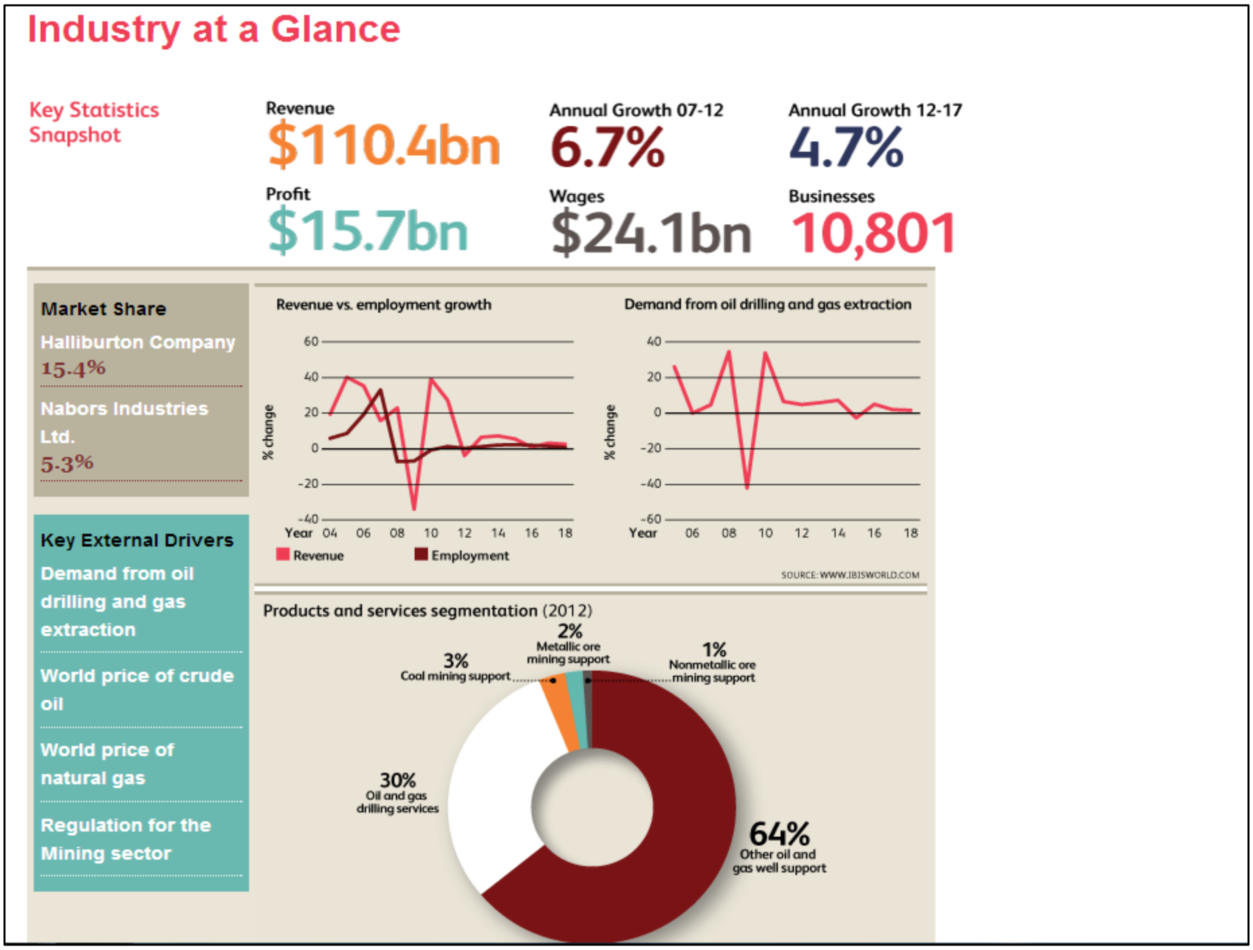
- Regular Size: $50
- Oversized: $75
- Plexiglass bottom housing $30
- Fasteners: $20
- Hopper: $50 (unless provided by Halliburton)

Called GH Distributing (1-800-658-3674) about Ultra Flyte flighting:

- New to market
- Only costs about 10% more than normal flighting, but it will last more than 10% longer
- Ultra Flyte 1" ½ shaft; RH twist; 5" flight; 3/16 wide; $7.17/ft
- Shipping approximately $35.00; ships out in a week
- 40% discount to manufactures
- Higher carbon content=more durable

*unless machined at material cost in OSU lab

Appendix H: Market Research



BADCo.

Appendix J: Screw Conveyors Reference

14.1 Screw Conveyors

Augers are used to convey materials that are free flowing, such as grain, as well as difficult fibrous materials and powders. For example, in a grain combine, augers are used to move cut crop on the platform to the feeder housing, clean grain from the bottom of the cleaning shoe to the grain tank, and to unload the grain tank onto a wagon or a truck. Augers are used at grain elevators and farmsteads to load grain storage bins and on feedlots for feed distribution.

14.1.1 Screw conveyor methods and equipment

The *screw conveyor* consists of a shaft that carries helicoid flightings on its outer surface. These flighting are enclosed either in a trough for horizontal augers or in a tube for elevating augers. The tube or the trough is held stationary while the rotation of the flightings causes the material to move longitudinally. Figure 14.1 shows the essential components of a screw conveyor. At the inlet side, the auger flightings extend beyond the tube. Generally, a hopper is provided to hold the material while it is conveyed into the tube. Augers can be permanently installed in a machine, or at a site, or they can be portable. The augers are driven either at the intake side or the discharge side. There are some center-drive augers but they are not common in agricultural applications.

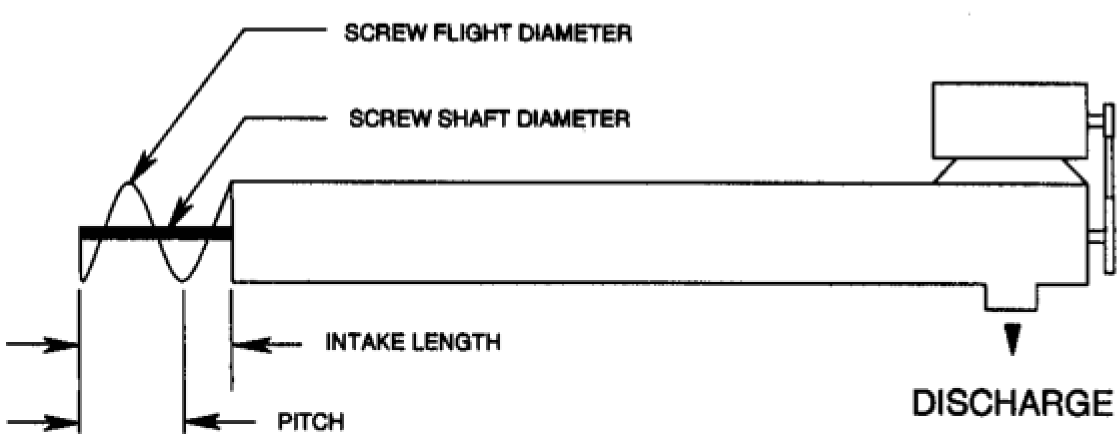


Figure 14.1 - A schematic diagram of a screw conveyor.

The auger length is defined as the length of the tube assembly including any intake but not including the intake hopper and/or the head drive. The intake length is the visible flighting at the intake of the auger. The outside diameter of the tube is referred to as the auger size. A standard pitch auger is the one whose pitch is approximately equal to the outside diameter of the helicoidal flighting. Generally, the pitch is not less than 0.9 and not more than 1.5 times the outside diameter. Standard pitch augers are used for horizontal and up to 20 degrees inclination angles. For inclination angles greater than 20 degrees, half-standard pitch screws are used. Double- and triple-flight, variable-pitch, and stepped-diameter screws are available for moving difficult materials and controlling feed rates.

14.1.2 Theory of screw conveyors

The *theoretical volumetric capacity* of an auger is expressed as:

$$Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n \quad (14.1)$$

where Q_t = theoretical volumetric capacity, m^3/s

d_{sf} = screw flighting diameter, m

d_{ss} = screw shaft diameter, m

l_p = pitch length, m

n = screw rotational speed, rev/s

In reality the actual capacity of an auger is considerably less than the theoretical capacity. This results in loss of volumetric efficiency. The *volumetric efficiency* is defined as:

$$\eta_v = \frac{Q_a}{Q_t} \quad (14.2)$$

where η_v = volumetric efficiency

Q_a = actual volumetric capacity, m^3/s

Generally, the throughput rate in terms of mass (or weight) per unit of time, for example t/h or kg/min, is specified. The volumetric capacity is obtained by dividing the throughput rate by the bulk density of the material.

The power requirement of an auger is expressed by the *specific power,* defined as:

$$P' = \frac{P/L}{Q_a \rho_b} \quad (14.3)$$

where P' = specific power, W s/kg m

P = power requirement, W

L = auger length, m

ρ_b = material bulk density, kg/m ^{3}

Thus, the specific power is the power required to convey a unit mass throughput rate per unit auger length.

The process of conveying by a screw conveyor is complex. It is difficult to develop analytical models to predict volumetric capacity and power requirements without making overly simplified assumptions. Purely empirical models, on the other hand, are not general enough in nature and cannot be used to predict auger performance in a variety of applications. Rehkugler and Boyd (1962) proposed the application of dimensional analysis as a tool to develop a comprehensive prediction model for screw conveyor performance. Table 14.1 shows a list of variables that are pertinent to the problem. These variables can be combined into ratios or dimensionless groups called the pi-terms using Buckingham's Theorem (see Chapter 1). The following equation includes the dimensionless terms:

$$\pi_1 = f\left(\frac{d_t}{d_p}, \frac{d_{sf}}{l_p}, \frac{d_{ss}}{l_p}, \frac{l_i}{l_p}, n\sqrt{\frac{l_p}{g}}, f(\theta), \mu_1\mu_2\right) \quad (14.4)$$

where $$\pi_1 = \frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n} \quad \text{or} \quad \frac{P/L}{Q_a \rho_b g} \quad (14.5)$$

Table 14.1. A list of variables affecting screw conveyor performance.

Symbol	Variable definition	Dimensions	Units
Q_a	actual volumetric capacity	L^3/T	m^3/s
P	power requirement	ML^2/T^3	W
d_t	tube inside diameter	L	m
d_{sf}	outside screw diameter	L	m
d_{ss}	screw shaft diameter	L	m
L	screw length	L	m
l_p	screw pitch length	L	m
l_i	exposed screw intake length	L	m
n	angular speed	1/T	rev/s
θ	angle of conveyor inclination	-	degrees
ρ_b	material bulk density	M/L^3	kg/m^3
μ_1	material-metal friction	-	-
μ_2	material-material friction	-	-
g	acceleration of gravity	L/T^2	m/s^2

The first term in the right hand side of Equation 14.5 is the ratio of the actual volumetric throughput rate to the theoretical volume swept by the screw per unit of time. This has been regarded as the volumetric efficiency of the screw conveyor. The second term in the right hand side of the above equation is the power required per unit length per unit mass flow rate of the material being conveyed. It has been defined as the specific power or the power efficiency of the conveyor. The conveyor length does not affect the volumetric efficiency.

The dimensionless terms of Equation 14.4 were used to develop prediction equations using experimental data. Published data on the performance of auger conveyors conveying wheat, oats, and shelled corn were used to develop the performance equations. These equations may be used to estimate conveyor performance for similar materials.

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\ l_p n} = (4.332\times10^{-4})\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{-0.44}\left(\frac{l_i}{l_p}\right)^{0.31}\left(f_1(\theta)\right)^{1.35}\mu_1^{-4.59}\mu_2^{-3.72} \qquad (14.6)$$

$$\frac{P/L}{Q_a\rho_b g} = 3.54\left(2\pi n\sqrt{\frac{l_p}{g}}\right)^{0.14}\left(\frac{d_{sf}}{l_p}\right)^{-10.12}\left(\frac{l_i}{l_p}\right)^{0.11}\left(f_2(\theta)\right)\mu_2^{2.05} \qquad (14.7)$$

where $f_1(\theta) = 1 + \cos^2\theta$ (14.8)

$f_2(\theta) = 6.94\,(1.3 - \cos^2\theta)$

θ = conveyor angle as measured from the horizontal, degrees

$0.414 > \mu_1 > 0.374$

$0.554 > \mu_2 > 0.466$

14.1.3 Screw conveyor performance

The performance of a screw conveyor, as characterized by its capacity, volumetric efficiency, and power requirements, is affected by the conveyor geometry and size, the properties of the material being conveyed, and the conveyor operating parameters such as the screw speed and the angle of inclination. The effect of these factors is discussed below.

14.1.3.1 Capacity

Screw length has no effect on the capacity of a screw conveyor. The effect of speed and inclination is given in Figure 14.2. As shown in the figure, there is a limiting value of speed beyond which the capacity does not increase. In fact, it may even decrease beyond a certain speed. It is also seen from this figure that the capacity decreases as the angle of inclination increases. The limiting value of speed is independent of the angle of inclination. It has been suggested that there may be two factors responsible for this behavior: (1) the maximum possible rate of grain flow through an orifice, and (2) the centrifugal force due to the rotation of the grain mass. Initially, the capacity increases directly with speed up to 250 rev/min. After this point the centrifugal force restricts the flow of grain at the intake and causes the slope to decrease. If the speed is increased sufficiently the centrifugal force may become so restrictive as to cause a decline in the capacity.

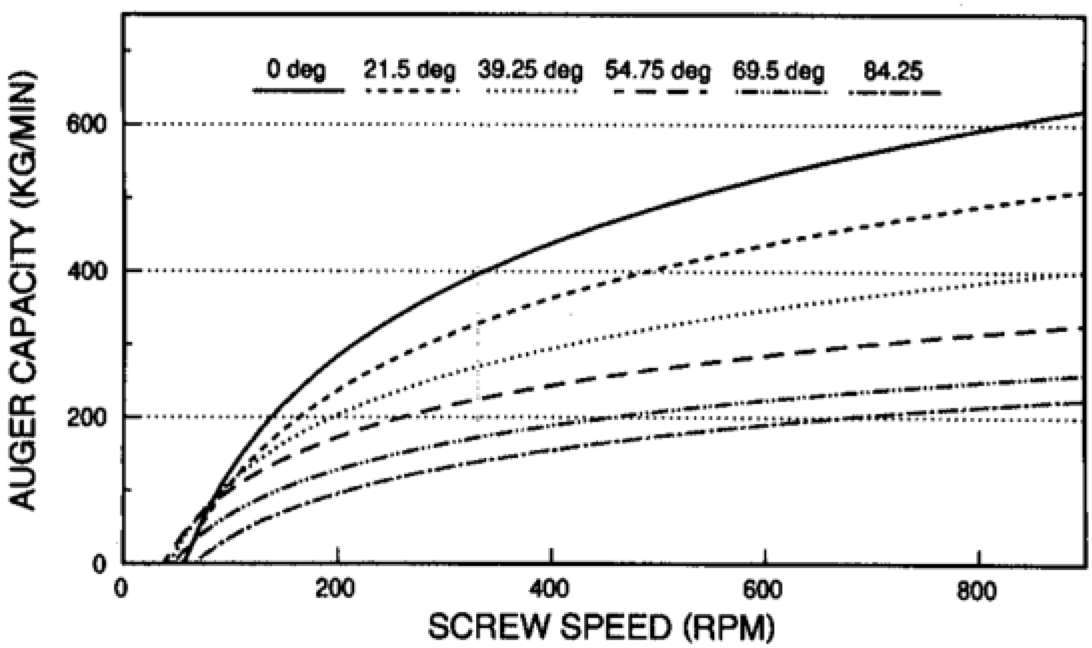


Figure 14.2 - Effect of screw speed and angle of auger inclination on conveying capacity (redrawn from Regan and Henderson, 1959).

Figure 14.3 shows the effect of screw angle of inclination on the capacity. The reduction in the capacity approximately follows the cosine function with two exceptions: (1) the capacity at higher speed is well below the cosine function, and (2) the capacity at 90 degrees angle is about 30% of the horizontal capacity. This may be due to the restriction to grain flow into the intake of the conveyor at higher speeds and the fact that grain flows from a vertical orifice at one-third the rate from a comparable horizontal orifice.

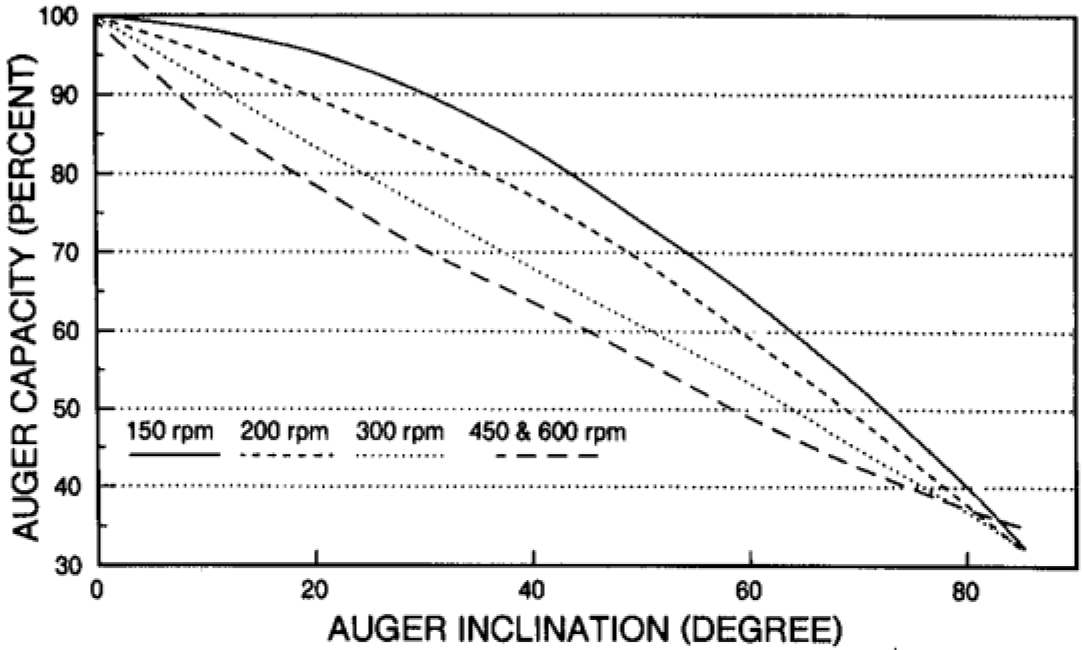


Figure 14.3 - Reduction in the auger conveying capacity as affected by the angle of inclination at different speeds (redrawn from Regan and Henderson, 1959).

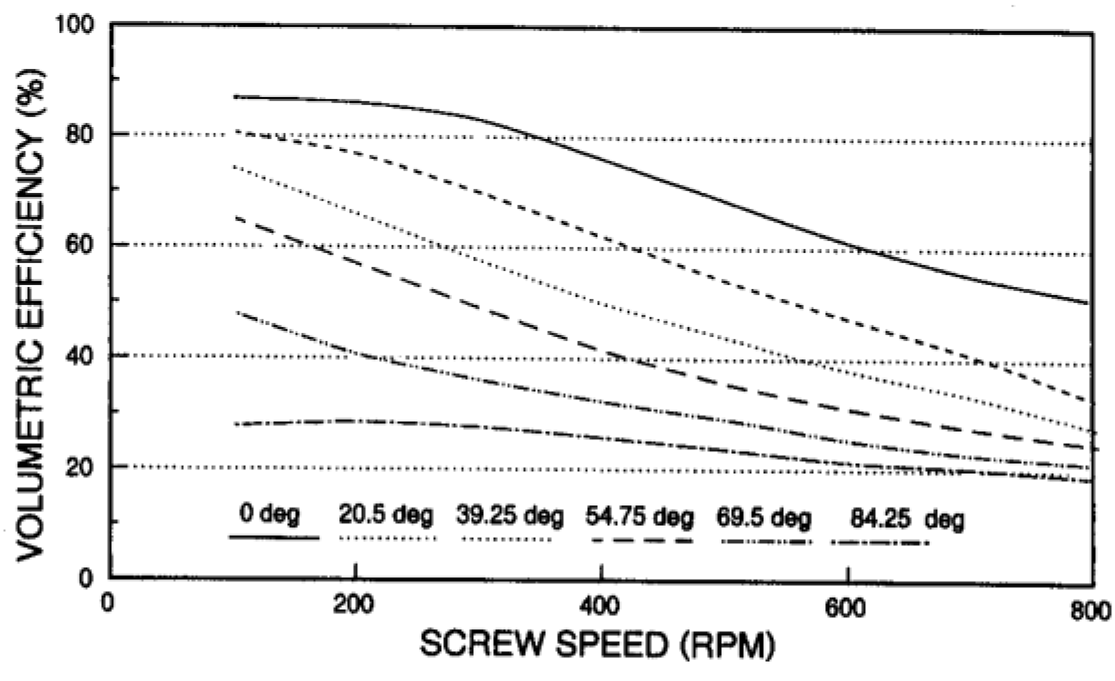


Figure 14.4 - Effect of screw speed on volumetric capacity at various angles of inclination (redrawn from Regan and Henderson, 1959).

14.1.3.2 Volumetric efficiency

Screw length has no effect on the capacity and volumetric efficiency of a screw conveyor. The effect of screw speed and inclination on volumetric efficiency is given in Figure 14.4. Generally, volumetric efficiency decreases as the screw speed and the angle of inclination increase. Brusewitz and Persson (1969) reported that the screw clearance affects the volumetric efficiency. As shown in Figure 14.5, the diametral clearances up to 5% to 7% have little affect on the volumetric efficiency, but a drop in efficiency of 0.7% per 1% increase in clearance can be expected. No interaction of the conveyor inclination and screw clearance is evident.

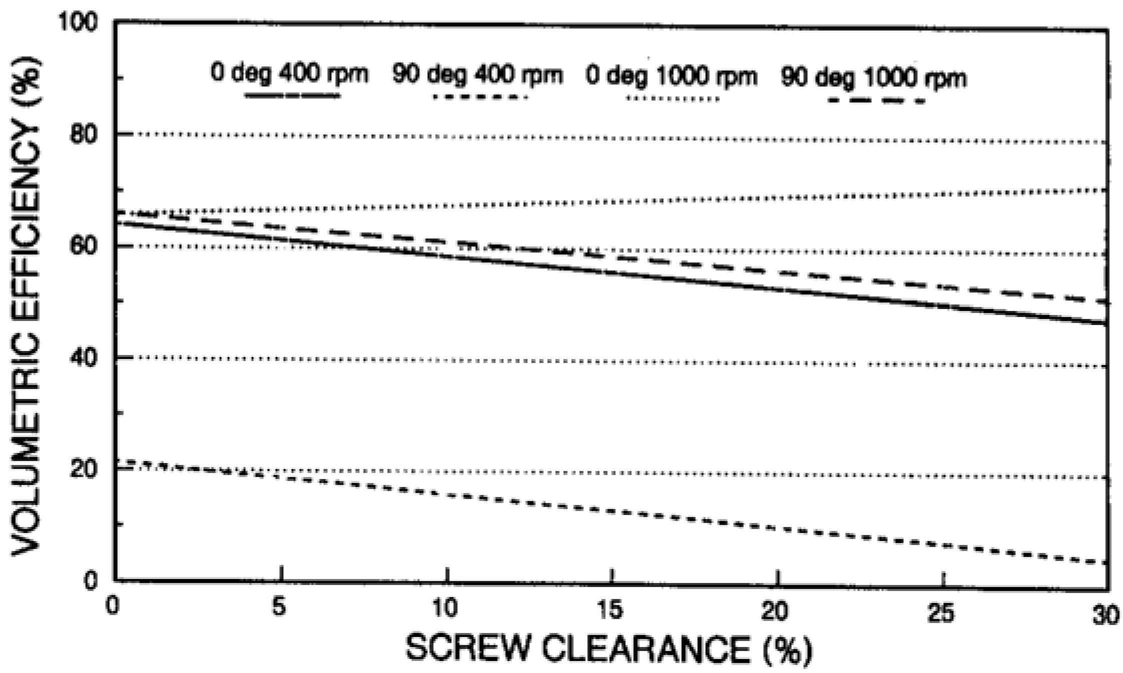


Figure 14.5 - Effect of the clearance between screw flightings and the tube inside diameter on the volumetric conveying efficiency (redrawn from Brusewitz and Persson, 1969).

14.1.3.3 Power requirements

The effect of screw diameter on specific power, as defined earlier, is dependent on the speed of a screw conveyor. At low speeds there is a decrease in the specific power with increase in the screw diameter. The trend reverses with higher speeds. Screw length has no effect on specific power. There is a slight effect of the pitch on the specific power. An increase in pitch tends to reduce the specific power. For horizontal augers, an increase in the diametral clearance causes a slight decline in the specific power. However, for vertical augers, this results in a general increase in the power. An increase in screw speed results in an increase in the required power as shown in Figure 14.6. The hump in the power curve below 300 rev/min is due to the high torque value at lower speeds. Increasing the angle of inclination causes the power to increase initially but a decrease follows beyond a certain angle. This is due to the decline in the volumetric efficiency. Moisture content that is associated with increase in friction causes the specific power to increase significantly.

Presently, concise data are not available for individual design problems. The selection is based on data provided by the manufacturers. Most data provided by the manufacturers are for low-speed horizontal augers. However, the equations given above may be used for estimating auger capacity and power requirements for a given application.

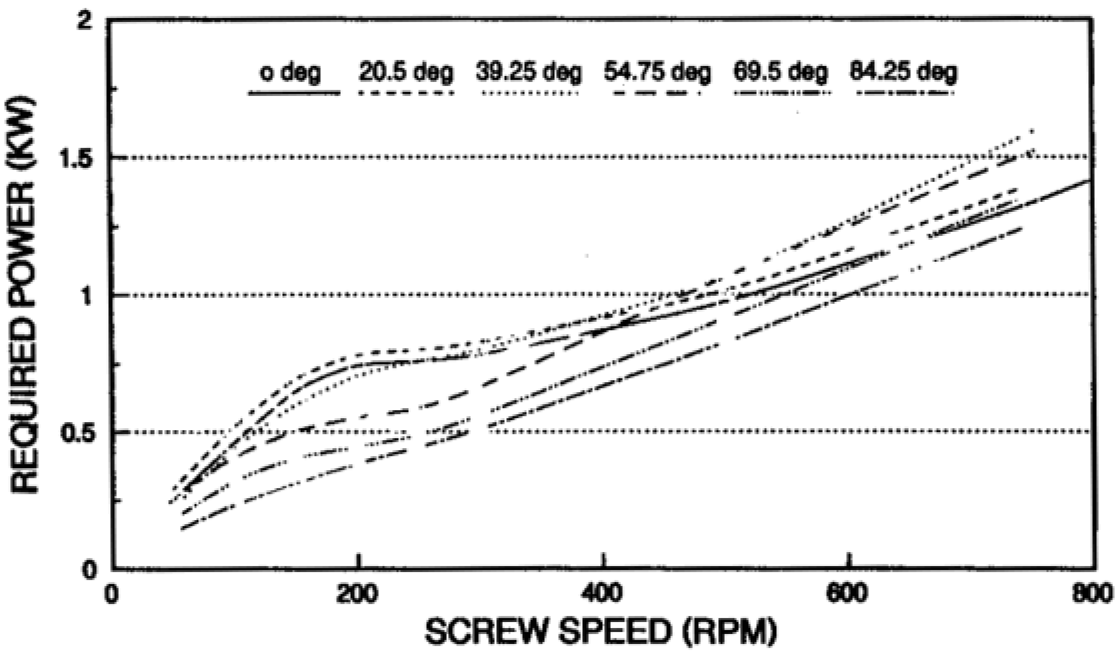


Figure 14.6 - Auger conveyor power requirements at different screw speeds and angles of inclination (redrawn from Regan and Henderson, 1959).

Example 14.1

Determine the efficiency, volumetric capacity, and power requirement of a horizontal standard pitch screw auger conveying wheat. The screw diameter is 15.24 cm (6 in.) and the shaft diameter is 2.54 cm (1 in.). The screw speed is 600 rev/min. The grain-metal friction may be taken as 0.414 while a value of 0.466 may be used for internal friction coefficient. The intake length of the screw is two times the pitch.

Solution

Given:	d_{sf} = 0.1524 m (6 in.)	μ_1 = 0.414
	d_{ss} = 0.0254 m (1 in.)	μ_2 = 0.466
	l_p = 0.1524 m (6 in.)	n = 10 rev/s (600 rev/min)
	l_i = 0.3048 m (12 in.)	θ = 0
	ρ_b = 769 kg/m ^{3} (Table 14.2)	

Table 14.2. Grain properties related to pneumatic conveying (ASAE Data D241.2).

Material	Bulk density, kg/m ^{3}	Particle density, kg/m ^{3}	Equivalent particle diameter, mm
Wheat	769	1300	4.08
Oats	410	1050	4.19
Barley	615	1330	4.05
Soybeans	769	1180	6.74
Corn	718	1390	7.26

Use Equation 14.6 to determine the efficiency. The dimensionless groups are calculated as follows:

$$2\pi n\sqrt{\frac{l_p}{g}} = 2\pi(10)\sqrt{\frac{0.1524}{9.81}} = 7.83$$

$$\frac{d_{sf}}{l_p} = \frac{0.1524}{0.1524} = 1$$

$f_1(\theta) = 2$

$$\frac{l_i}{l_p} = \frac{0.3048}{0.1524} = 2$$

Substituting in Equation 14.6 we get:

$$\frac{Q_a}{\frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right)\ l_p n} = (4.32\times 10^{-4})(7.83)^{-0.44}(2)^{0.31}(2)^{1.35}(0.414)^{-4.59}(0.466)^{-3.72}$$

$= (4.32 \times 10^{-4})(0.404)(1.24)(2.55)(57.3)(17.12)$

= 0.541

η_v = 0.541 or 54.1%

Volumetric capacity can be found as:

$$Q_a = 0.541\frac{\pi}{4}\left[(0.1524)^2 - (0.0254)^2\right](0.1524)(10) = 0.0146\,m^3/s\,(\text{or } 40.5\,t/h)$$

Use Equation 14.7 to determine the power requirement.

$$\frac{P/L}{Q_a \rho_b g} = 3.54(7.83)^{0.14}(1)^{-1012}(2)^{0.11}(2.082)(0.466)^{2.05}$$

= 3.54(1.334)(1)(1.079)(2.082)(0.209) = 2.217

P/L = 2.217(0.0146)(769)(9.81) = 245 W/m

Appendix J: Resumes

Résumés of Team Members

The following pages present two-page résumés of the team members for this project.

Colt Medley

2139 E. 100th St. N. Wagoner, OK 74467
(918)-645-0038
colt.medley@okstate.edu

Objective

- Seeking a full time position in an Engineering or Petroleum Exploration and Production field.

Skills

I can create advanced 3-D components and assemblies in Solid Works and have a good understanding of Finite Element Analysis. I also am proficient in Cad Key.

Proficient in Microsoft Word, Excel, Vba, and PowerPoint

Education

- **3.67 Technical GPA**
- Bachelors of Science Degree in Biosystems Engineering- Mechanical Option
- Minor in Petroleum Engineering
- Graduation from Oklahoma State University Date- May 2013

Relevant Experience

Engineering Intern **Ren Corporation** **Fall 2012-Present**

Assisted engineers and worked with a team of professionals who assemble million dollar hydraulic testing machines for companies all over the world. There I work with Cad Key and Solid Works assisting in the production of schematics for the machines.

Assistant Forman **Parents House** **Summer 2012**

Assisted in the construction of my parents' house. We started from an empty steel building I fabricated all the corrals, corner posts, and an archway, framed bedrooms, doorways and windows. I wired our home, plumbed the barn, operated heavy machinery for the formation of roads, sheet rocked the garage, laid hard wood floor in the whole house.

Assistant Wrangler **Lone Tree Bible Ranch** **Summer 2006 to 2009**

At Lone Tree Ministries we used the outdoors and adventure based activities to share Christ with each camper in a gentle, natural way through personal attention and relationships built through the activities. During the duration of two months in the summer, I took care of the horses which consisted of grooming, feeding, training, assisting other wranglers on the trail rides, and overnighters out and camp in the open prairie where we contribute to the personal relationships of campers with Jesus Christ. www.lonetreebibleranch.com

Horse Trainer & Farm Hand **Family Farm** **1997-Present**
Trainer at Shining M shooters ranch of many world class shooting, team roping, and reining horses from a vast number of clientele, over thirteen years of experience. Operating and repairing necessary machinery such as tractors, power tools, implements, etc. Perform chores, build fence and maintain structures.

Honors and Activities
American Association of Directional Drillers
Several Honor Roll certifications
Honors Scholarship for Academics Tulsa Community College (2008-2010)

References Available Upon Request

Tim Hunt
221 S. Washington St. Apt 2 ♦ Stillwater, OK 74074 ♦ 913-375-3623 ♦ tim.hunt@okstate.edu

OBJECTIVE: **Seeking an internship to gain experience in designing and developing sustainable energy and agricultural resources.**

SUMMARY: **A Biosystems and Agricultural Engineering student with an emphasis in Biomechanical design. I have taken courses that cover topics such as machinery processing, mechanical power, microbial technologies, and instrument circuitry. I have experience using design software such as Pro-Engineering and Solid Works.**

Education

Oklahoma State University, Stillwater, OK — Aug 09-Dec 13

Bachelor of Sciences in Biosystems and Agriculture Engineering (Biomechanical emphasis)
Spanish Minor
Cumulative GPA: 2.7/4.0

Qualifying Skills

Pro-Engineer Software
Solid Works Software
Arduino Programming
Basic Stamp II Programming
Visual Basic for Applications
Microsoft Office Applications
Residential Construction
Small Engine Repair and Maintenance

Clubs and Organizations

American Society of Agriculture and Biological Engineers (ASABE)
Cowboy Motorsports (1/4 Scale Tractor Competition)
International Social Fraternity

Leadership Experience

ASABE Student Branch — *Spring '12-Present*
Oklahoma State University, Stillwater, OK
CASNR Representative

Involvement in International Social Fraternity — *Fall '09-Present*
Oklahoma State University, Stillwater, OK
Member Recruitment Chair
Sergeant at Arms
Scholarship Board

Professional Experience

Eskimo Joes, *Bartender,* Stillwater, OK *May 11-Present*

Utilize communication skills with managers, co-workers, and customers.

Practice prompt service and response time to satisfy guests.

Schlitterbahn Vacation Village, *Lifeguard,* Kansas City, KS *May 10-Aug. 10*

Earned lifeguard certification.

Participated in weekly customer service protocol seminars.

Seal of Approval Landscaping, *Laborer,* Kansas City, KS *May 05 – August 09*

Renovate houses, landscaping labor, snow removal.

Practice small engine repair and maintenance.

Tarron Ballard

9216 S. Rose Rd. | tarron.ballard@okstate.edu
Perkins, OK 74059 | Tarron Ballard | (918)-509-0547

Objective:

To obtain a career as an Engineer in the oil and natural gas industry

Skills and Accomplishments:

Engineering Internship with Weatherford International
Study Abroad Class: Technologies of Brazil
Senior Design Project with Halliburton

Education:

Bachelor of Science in Biosystems Engineering — May 2013
Minor in Petroleum Engineering
Oklahoma State University
GPA: 3.11/4.00

Professional Experience:

Engineering Internship — May 2012-July 2012
Weatherford International, Completions Department
Took completion courses and packers practical rig applications class
Helped rebuild packers in the shop
Went to locations with tool hands and helped run plug and packer jobs

Cashier, Parts Specialist — 2011-Present
Napa Auto Parts-Main Auto Supply
Responsible for helping customers find what they need and making sells
Make deliveries to customers
Keep shelves stocked and up to date

Carpet Cleaner — 2009-2011
Short's Carpet Cleaning
Responsible for driving the van and cleaning machine to the customer's home
Discussed job requirements with customer and gave customer quote for the job
Cleaned the carpet to the customer's satisfaction
Responsible for collecting payment and carrying up to $500

Maintenance Worker — May 2009-July 2009
Cimarron Trails Golf Course
Responsible for taking care of the club house lawn

Installed sprinkler systems
Mowed and any miscellaneous work needed

Day Manager August 2008-May 2009
Edge Tanning Salon
Responsible for opening and closing
Sold tanning packages and tanning products
Responsible for closing daily transactions and dropping of deposits at the bank

Assistant Cabinet Maker May 2008-August 2008
DJ Cabinets
Responsible for painting, staining and lacquering cabinets
Built drawers, doors, shelves and assisted in building cabinets
Responsible for delivering and installing the cabinets

Activities:
Study Abroad Class: Technology of Brazil
Volunteer at LifeChurch.tv Stillwater

Honors:
Dean's Academic Excellence Scholarship 2011 and 2012
Academic Excellence Scholarship
Blair and Mary Stone Scholarship
Honors Classes:
Engineering Computer Programming
American Government

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OPTIMIZING AUGER OUTPUT

BADco.

Colt Medley
Tarron Ballard
Tim Hunt

HALLIBURTON

- Founded in 1919 by Erle P. Halliburton in Duncan, OK.
- Started as a company specializing in cementing products.
- Has grown to one of the world's largest product and service providers.
- Employs over 70,000 workers in about 80 countries.
- Supports upstream oil and gas industry in many ways
  - Managing geological data
  - Drilling and formation evaluation
  - Well construction and completion
  - Optimizing production throughout the life of the well

HALLIBURTON

FB4K BLENDER

- 60 to 80 percent of all wells drilled in the United States in the next ten years will require hydraulic fracturing to remain in production.
- Halliburton uses the FB4K Blender to mix proppant and liquids before they are pumped into a well.
- FB4K Blender:

FB4K BLENDER

- Each system costs up to $1M to produce.
- Each sand screw costs around $20K.
- Proppant costs from $1.50 to $7.00 per pound.
- Each job can take from 250,000-1,000,000 pounds of proppant.
- Average lifetime of each screw is around 15 years.
- FB4K Blender:

OTHER BLENDERS

OTHER BLENDERS

- National Oilwell Varco - MT-1060 Trailer Mounted Blender
  - Based out of Houston.
  - Choice of twin or triple field tested and calibrated proppant augers in several available configurations and sizes.
  - Max output not published.

MT-1060 Blender equipped with eight (8) precision chemical metering systems

OTHER BLENDERS

- SERVAgroup- BSTLR-321A Trailer Mounted Blender
  - Stimulation products based in Duncan, OK.
  - Features an automatic and manual control system in case of system failure.
  - The automatic system features 3 modes of operations that provide the operators with constant system performance data via on-board screens.
  - Max output not published.

OTHER BLENDERS

- JEREH HSC 300
  - Company based in China.
  - Equipped with an automatic control system developed independently by Jereh.
  - Two 12” augers, one 8” auger.
  - Max convey rate: 12,713 cubic feet per hour.

OTHER BLENDERS

- Tacrom- Blender II
  - Used mostly for gravel-pack jobs, but can be used for anything slurry-related.
  - The equipment is fully single man operated, including all valves being controlled from a control panel mounted in a climate controlled cabin.

OTHER BLENDERS

- NRG : 1320 BPM Blender
- NRG based out of Houston.
- Two 12” augers, one 6” auger.
- Offers a complete automated and control system.
- Max output not published.

PROBLEM DEVELOPMENT

PROBLEM

- Project Proposal:
  - Augers are used to meter proppant into the mixing tub on the FB4K.
  - Over a certain speed, the output is not linear.
  - We will optimize the design to increase the linear output operating range.

Augers:

PROBLEM STATEMENT

- "Our project is to improve the accuracy and output of the FB4K Blender's sand screws. This is to be done by providing an equation that describes the output of the current design, as well as proposing a new, more efficient design for the sand screw to possibly be implemented on the FB4K Blender. The most important factors affecting design are: increase in output, ability to be integrated with existing system, cost of integration, and durability of design."

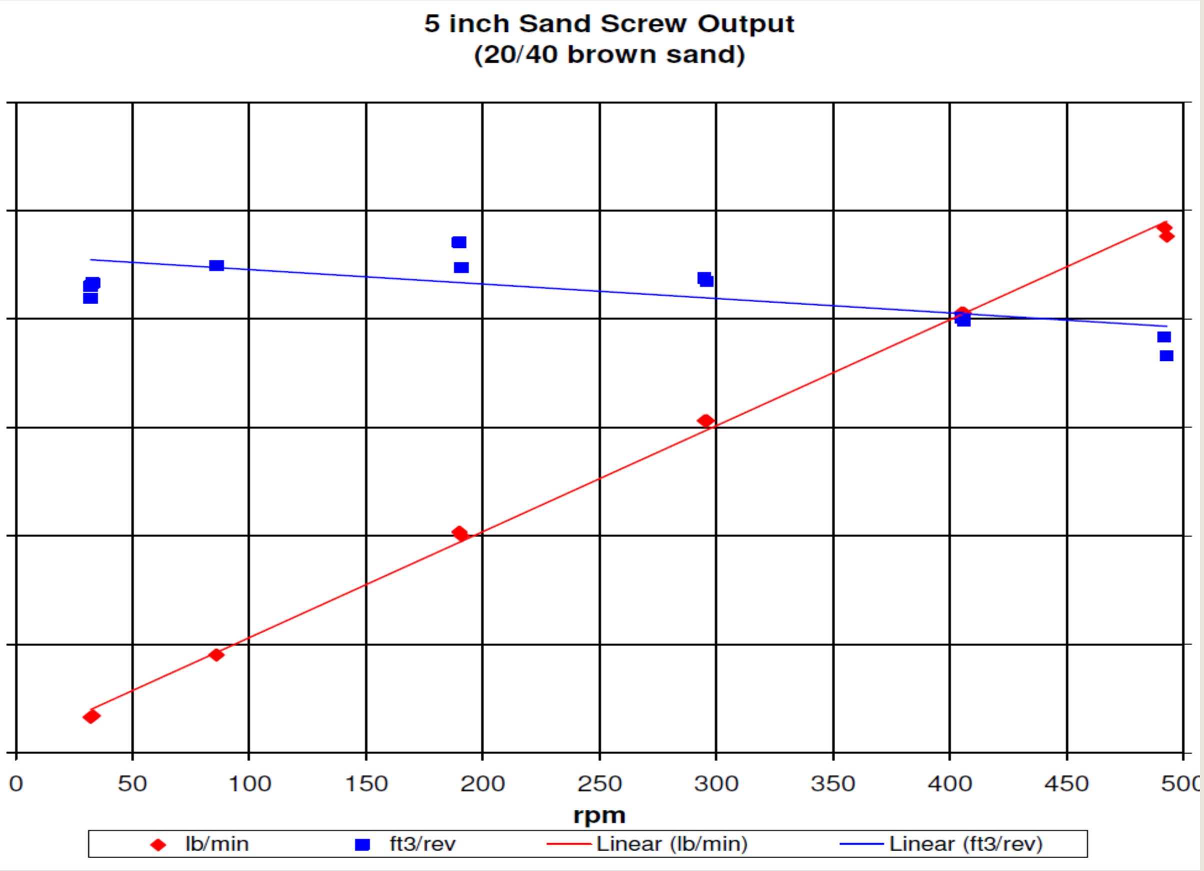
OBJECTIVES

- Utilize current test data to derive an equation that describes loss in output.
- Propose design changes that will improve overall output.
- Build a prototype of one (or more) proposed design(s).
- Test prototype using different grades of commonly used proppants.
- Review prototype test data to determine the accuracy of new design.
- Derive an equation that describes the newly designed auger's output.

DEVELOPING OUTPUT EQUATION

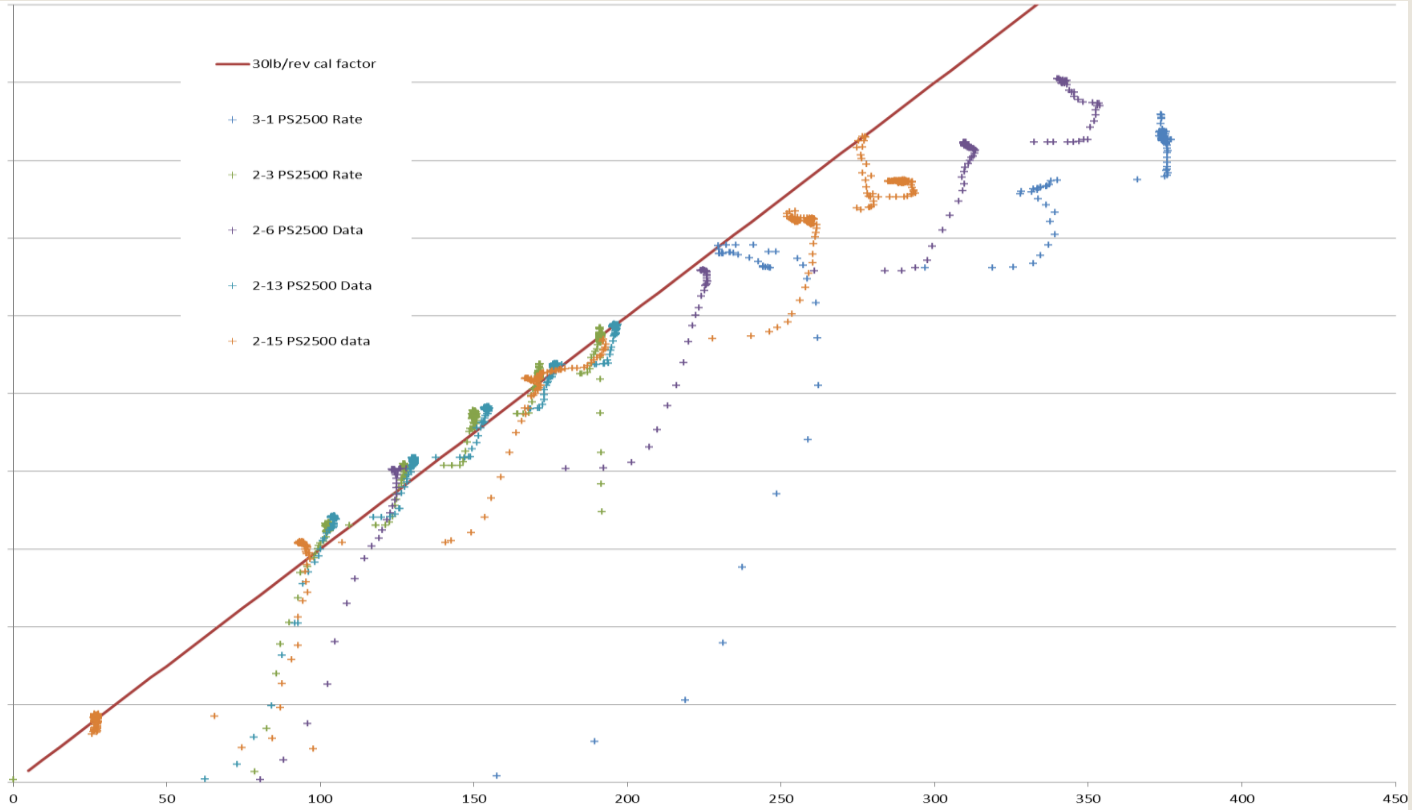
CURRENT DESIGN

- One 6” diameter, 11’ long auger, 4”-6” pitch
- Halliburton test data:



CURRENT DESIGN

- Two 12” diameter, 11’ long augers, 8” – 12” pitch
- Halliburton test data (one auger):



CURVE MODELING

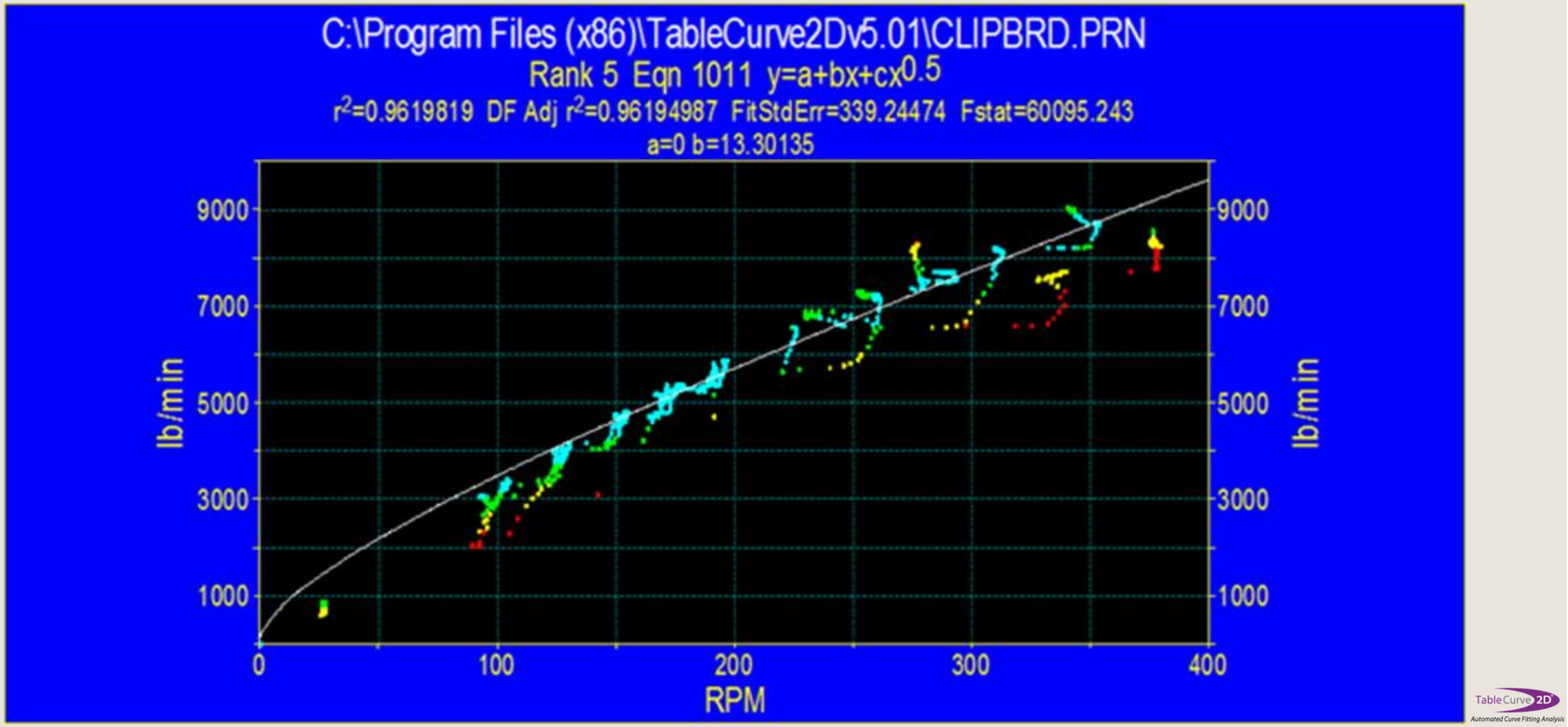
- Used Table Curve software to produce best-fit equations.
- Data was taken from the 12" auger data.
- Outliers were not included.
- Low order equation is preferred for ease of integration.

TableCurve 2D®

Automated Curve Fitting Analysis

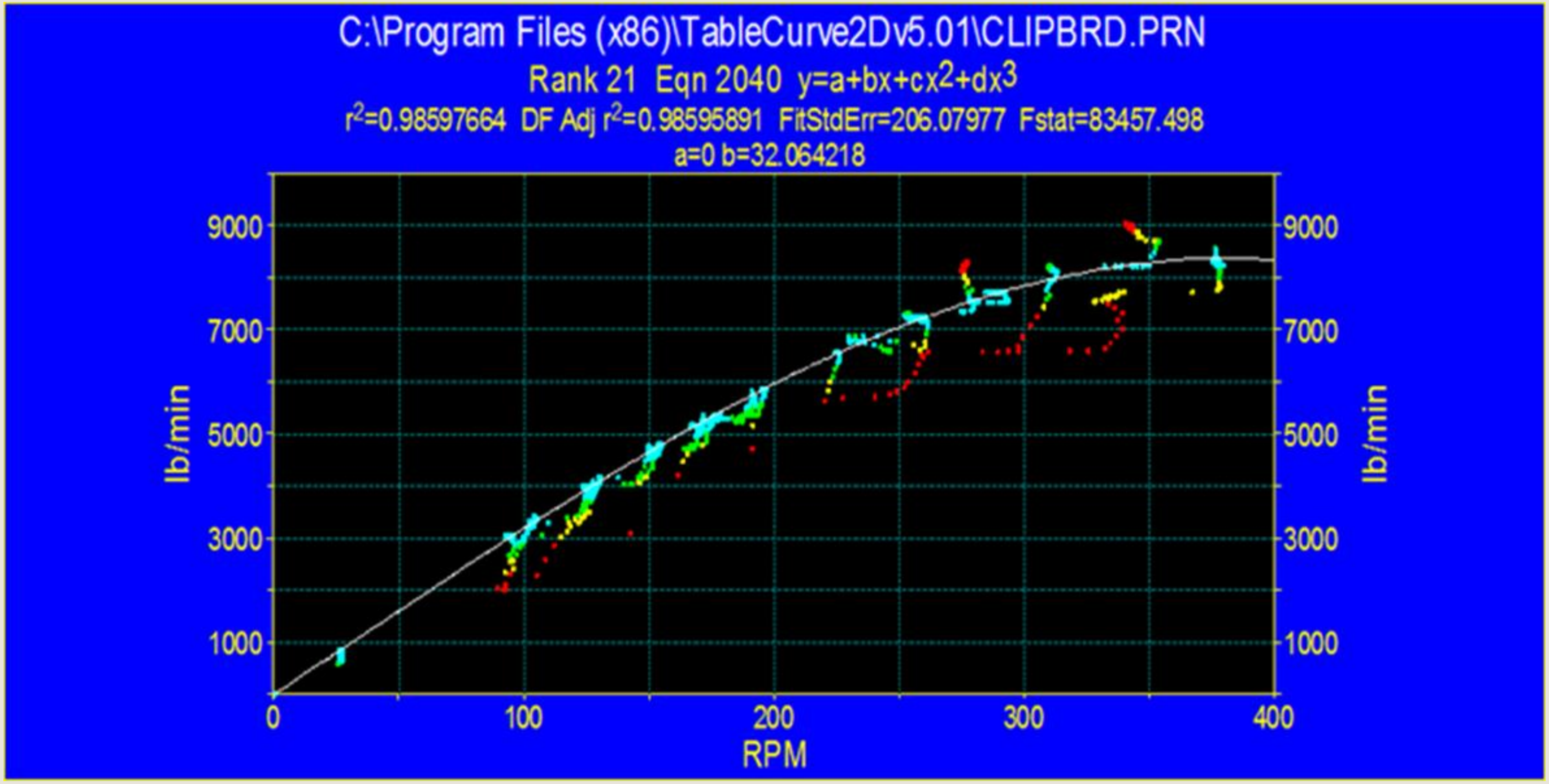
CURVE 1

- Accurate from 150-300RPM.
- Slightly decreasing slope throughout curve.



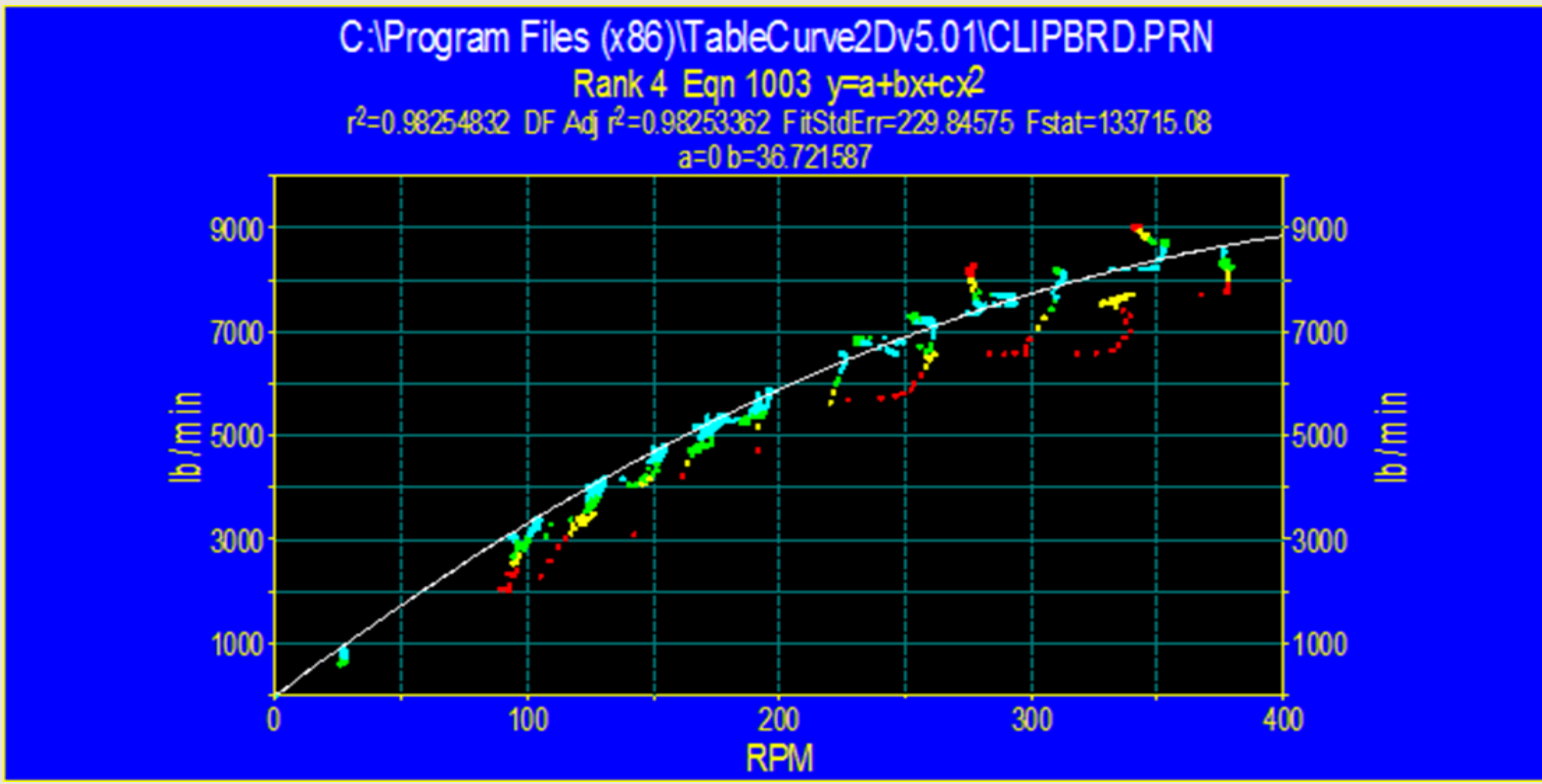
CURVE 2

- Very accurate at all RPMs.
- Slope becomes negative after 375RPM.

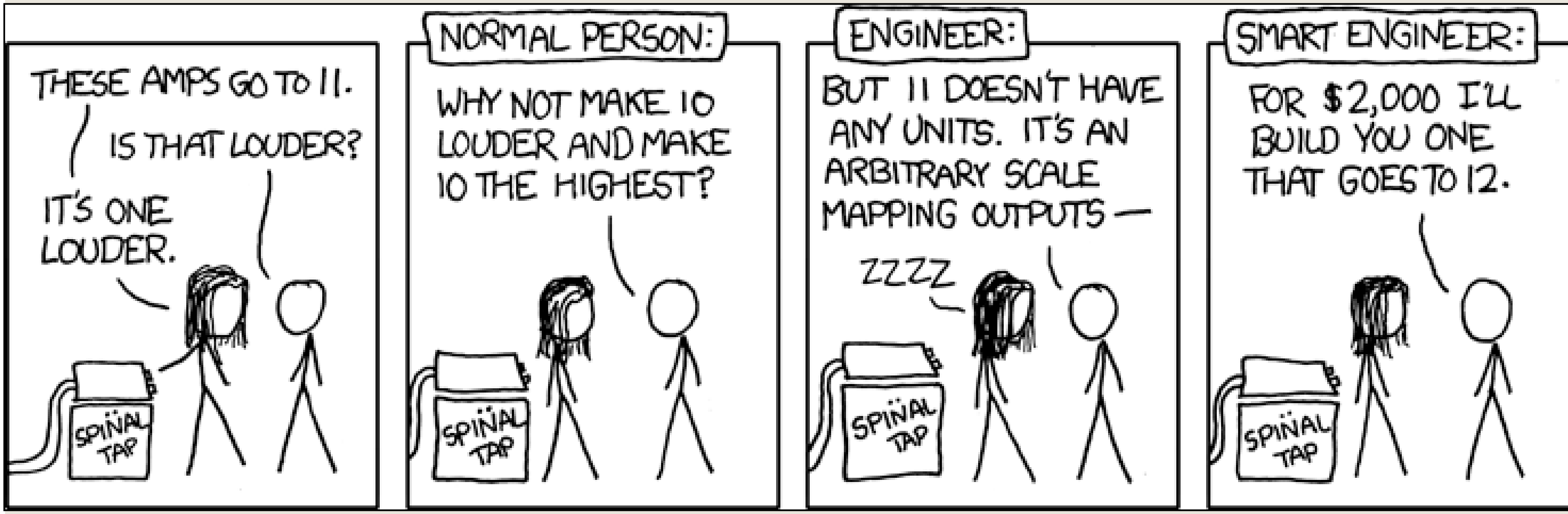


CURVE 3

- Accurate at all RPMs
- Slope stays positive, but keeps decreasing at high RPMs.



REDESIGN


THESE AMPS GO TO 11.
IS THAT LOUDER?
IT'S ONE LOUDER.
SPINAL TAP
NORMAL PERSON:
WHY NOT MAKE 10 LOUDER AND MAKE 10 THE HIGHEST?
SPINAL TAP
ENGINEER:
BUT 11 DOESN'T HAVE ANY UNITS. IT'S AN ARBITRARY SCALE MAPPING OUTPUTS —
ZZZZ
SPINAL TAP
SMART ENGINEER:
FOR $2,000 I'LL BUILD YOU ONE THAT GOES TO 12.
SPINAL TAP

DEVELOPMENT OF DESIGN CONCEPTS

WHAT'S CAUSING THE PROBLEM?

- Possible issues in the hopper:
  - Not feeding auger fast enough
  - Not completely filling up bin
  - Proppant doesn't have time to surround screw completely at high RPM
  - Vertical angle may allow gravity to pull proppant away from tube
  - Auger housing extends into the hopper, limiting availability of proppant
- Possible issues with auger:
  - Pitch and flighting too big/small
  - Flight cross section not optimized
  - Distance between flights and tube
- The drive mechanism was not explored as a possible issue.

HOPPER SOLUTIONS

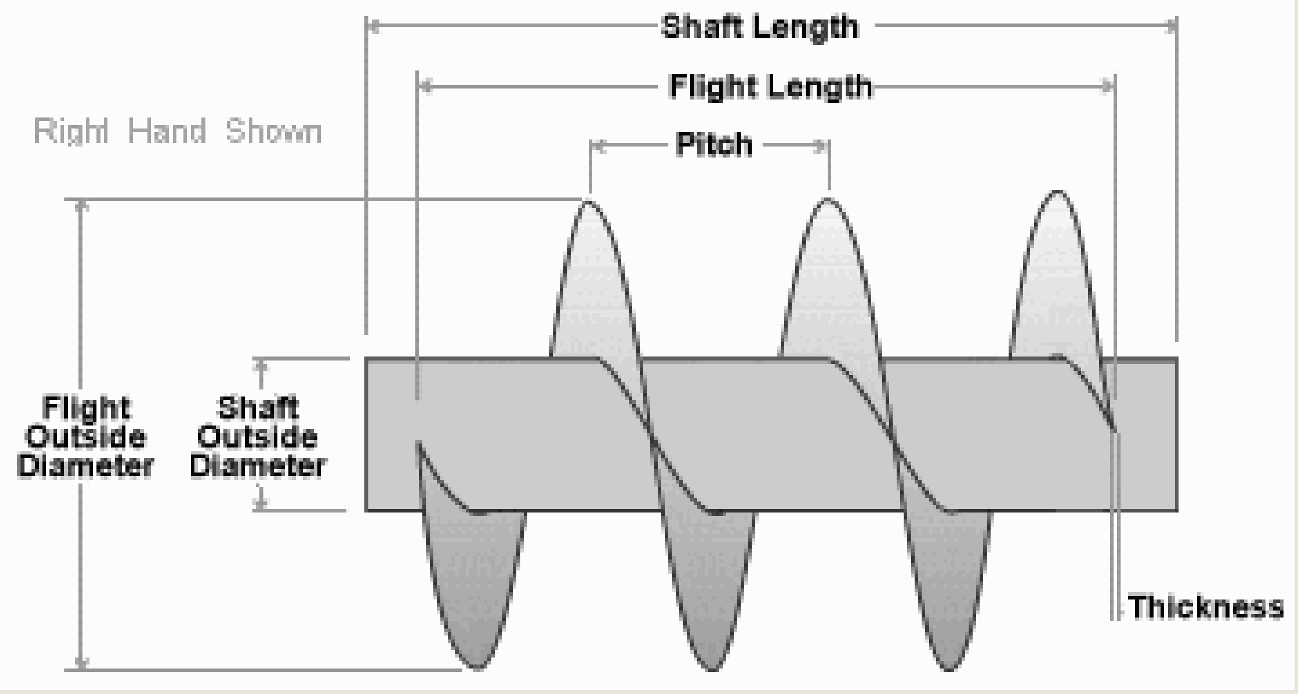
- Increase size of auger
  - Bigger hopper=More available proppant
- Add a horizontal screw/bin
  - Allows room for multiple screws

HOPPER SOLUTIONS

- The auger housing extends one foot into the hopper.
- This covers up part of the screw that could be exposed to more proppant in the hopper.
- Remove the tube from inside the hopper to increase the amount of proppant available to the screw.

AUGER SOLUTIONS

- Increase pitch length
  - Proppant will have more time to fall to the bottom between rotations.
  - Proppant will fill volume more efficiently, improving accuracy of output.



AUGER SOLUTIONS

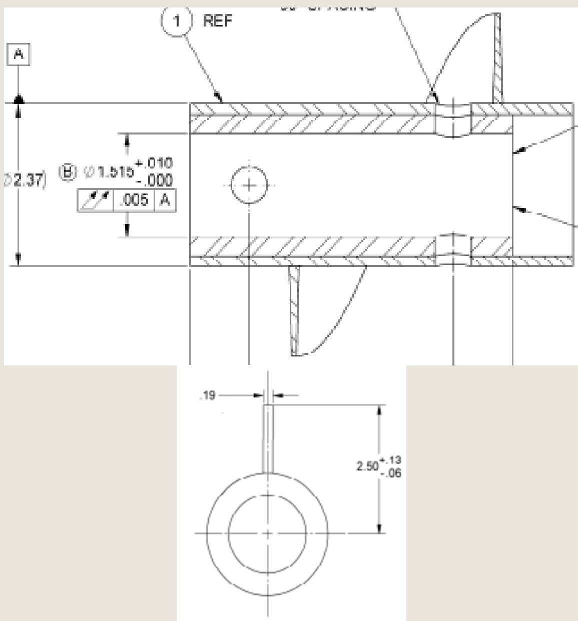
- Increase flight size/decrease tube size
  - Tighter distance tolerance between screw and surrounding tube
  - Less sand can escape the radius of the auger's flights
  - Increased output accuracy

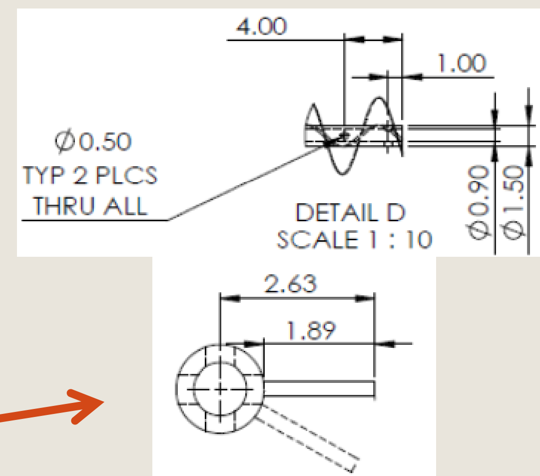
AUGER SOLUTIONS

- Increase flight size/decrease tube size
  - Tighter distance tolerance between screw and surrounding tube
  - Less sand can escape the radius of the auger's flights
  - Increased output accuracy

AUGER SOLUTIONS

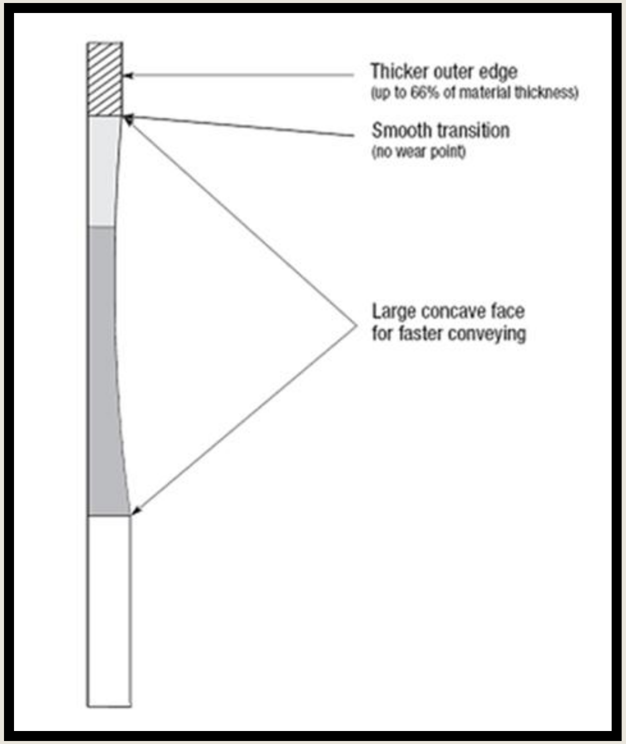
- Decrease shaft size in 6 inch auger.
  - 12” auger shaft: 2 7/8”
  - 6” auger shaft: 2 3/8”
- Decreasing the outer diameter of the shaft to 1 ½” will allow more space inside the tube for proppant to be delivered.





AUGER SOLUTIONS

- Change cross section design of flights.
  - Implement concave flight design.
  - Allows for more volume to be moved per rotation.
  - Improve durability, overall output.
  - Possibly improve linearity at high RPMs.
    - Concave design should be able to hold more material at high RPMs.



ULTRA FLYTE

- http://www.youtube.com/watch?v=HeJelaRcOAw

CADORATH
UNIFLYTE

CRITERIA

- Design Acceptance Criteria:
  - Increases overall output
  - Increases linear range of operation
  - Ease of integration with current system
  - Ease of implementation
  - Cost of implementation and integration
  - Ability to be combined with other designs
- Choose the design that accounts for all of these criteria most closely.

OUR SOLUTION

- Our solution is the integration of several designs.
  - Decreased shaft diameter
  - Use of concave flighting
  - Removal of tube extension into hopper

- Solution allows multiple designs to be utilized.
  - Designs will be tested independently

SUPPORTING DATA

ENGINEERING SPECIFICATIONS

- 6” auger connected to 5 hp source
- Torque = Power / Angular Velocity

  5hp / 600 RPM = 275 ft·lb torque (max)
- Theoretical Volumetric Output: $Q_t = \frac{\pi}{4}\left(d_{sf}^2 - d_{ss}^2\right) l_p n$

  $Qt = (\pi/4)\ (5^2 - 2.375^2)in^2\ (6in)\ (300RPM) = 22807\ in^3/min = 13.1ft^3/min$
- For 100 lb/ft^3 proppant,

  theoretical *mass* output rate = 1310 lb/min
- Using Halliburton’s test data, efficiency is calculated as: $\eta_v = \frac{Q_a}{Q_t}$

  $\eta_v = 615 / 1310 = 47\%$
- Hopper volume:
  - 114.16 in^3

DESIGN SOLUTION DATA

- 12” auger with 2.875” OD shaft and 15 hp drive
  - Torque @ 600 RPM = 825 ft·lb
  - Output = 92.23 ft^3/min
- 6” auger with 2.375” OD shaft and 5 hp drive
  - Torque @ 600 RPM = 275 ft·lb
  - Output = 13.1 ft^3/min
- When shaft size is decreased to 1.5” OD:
  - Output = 18.61 ft^3/min
  - 42% increase in output volume
- Hopper volume without flange:
  - 214 in^3
  - 88% increase in hopper volume

BUDGET

- Halliburton has offered us a budget of $5000-$10,000.
- Four auger's needed
  - Control
  - Ultraflyte
  - Extended Pitch
  - Decreased Shaft OD
- Two Bins Needed
  - One normal
  - One oversized
- Total estimated cost: $3000

Part:	Cost:
flighting	$100
shaft	$40
housing	$200
housing bracket	$75
bin	$75
plexiglass bottom housing	$30
hopper	$50
upper shaft	$100
bottom shaft	$100
bearing support plates	$50
bearing	$50
bearing housing	$30
output chute	$40
discharge support	$50
transmission plates	$100
test stand	$150
fasteners	$125
hydraulic variable drive	$500

COST ANALYSIS

Discount Rate **4.00%**

Year	0	1	2	3	4	5
Gross Margin		$3,000	$3,030	$3,060	$3,091	$3,122
Discount Factor	1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
PV of Savings	$0	$2,885	$2,801	$2,721	$2,642	$2,566
Total Expense	$5,000	$0	$0	$0	$0	$0
Less Depreciation and Term Interest		$0	$0	$0	$0	$0
Cash Expenses	$5,000	$0	$0	$0	$0	$0
Discount Factor	1	0.961538462	0.924556213	0.888996359	0.854804191	0.821927107
PV of Expenses	$5,000	$0	$0	$0	$0	$0
Benefits Less Costs	($5,000)	$3,000	$3,030	$3,060	$3,091	$3,122
PV Benefits Less PV Costs	($5,000)	$2,885	$2,801	$2,721	$2,642	$2,566

Total PV of Income	$13,615
Total PV of Expenses	$5,000
Net Present Value	$8,615
Internal Rate of Return	53.63%
PV Benefit/PV Cost Ratio	2.72
Payback Period (years)	1

(payback period only displayed if less than 10 years)

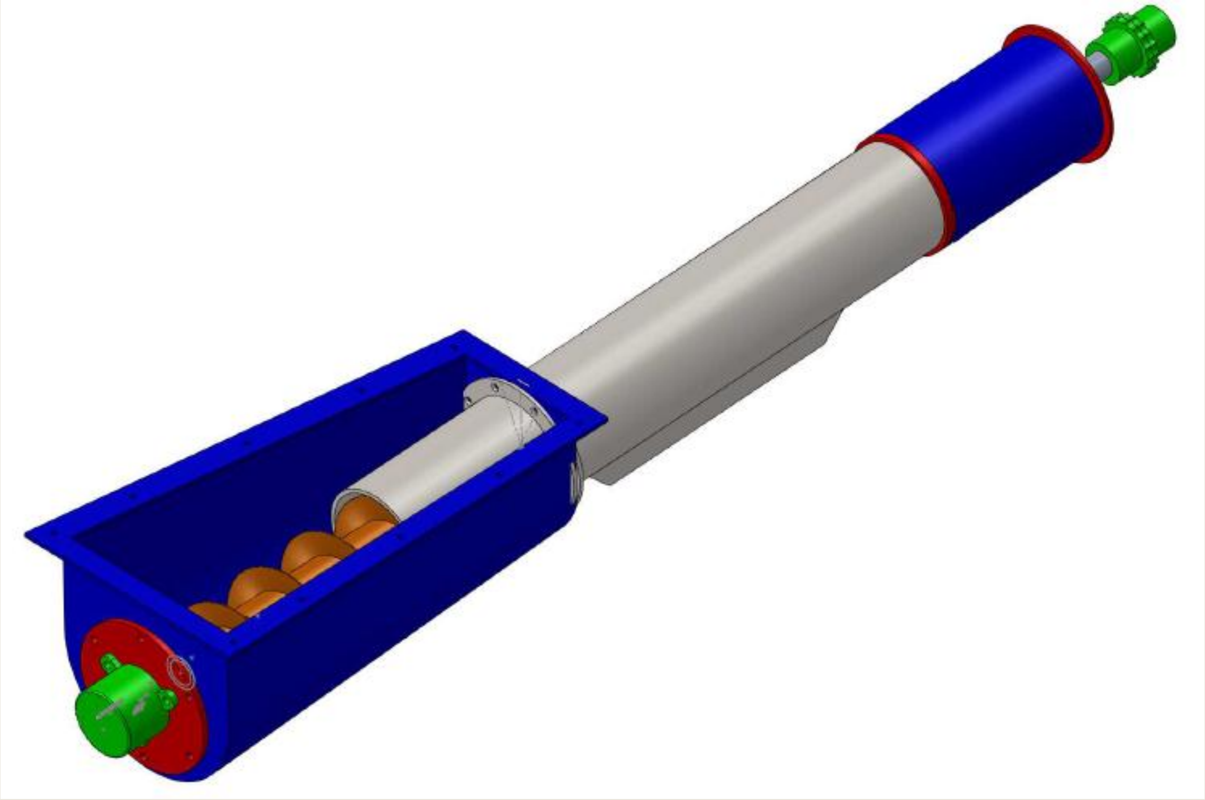
PROTOTYPE TESTING

TESTING

- We will produce an auger identical to Halliburton's six inch design that is shorter in length. This will provide us with a control test.
- There are several design prototypes that will be tested at multiple speeds
  - Hopper Design
  - Decreased shaft OD
  - Flight pitch length
  - Flight cross section (UltraFlyte)

PROTOYPE

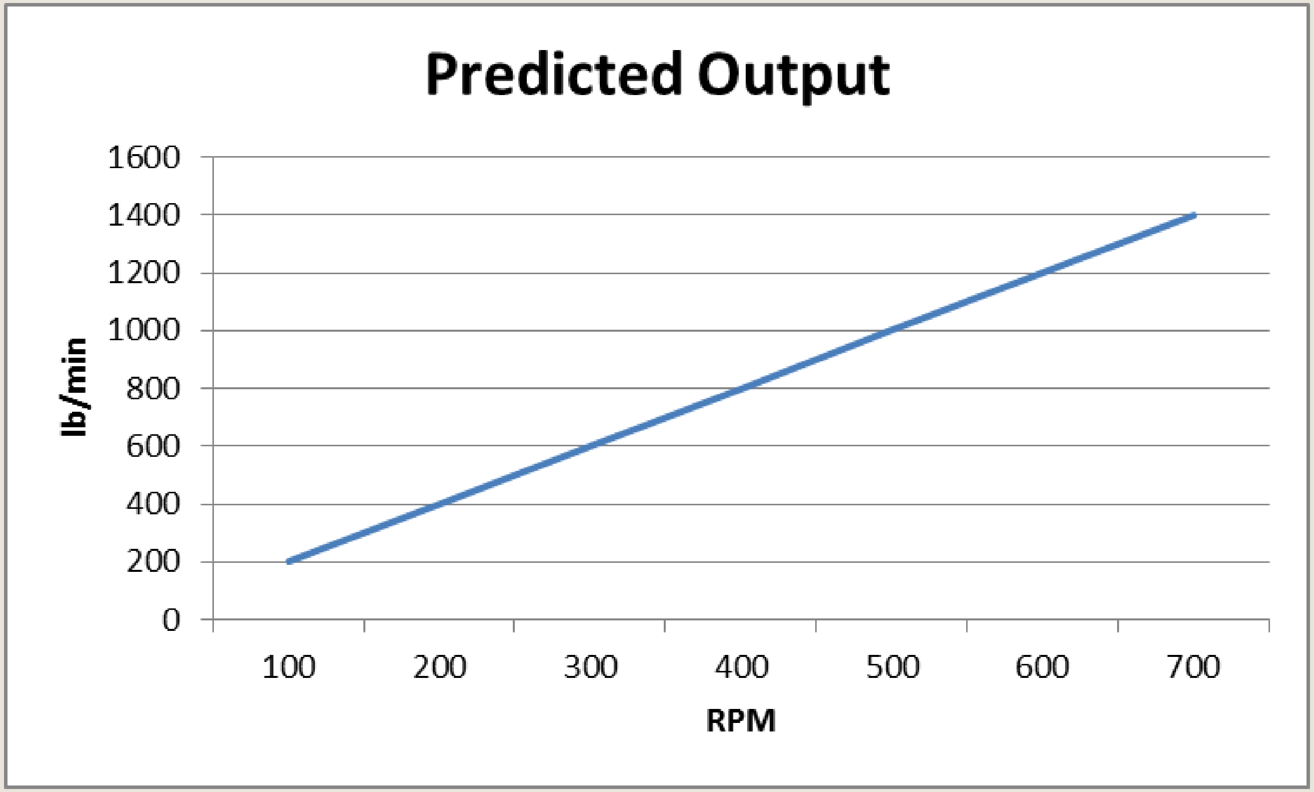
- Control Auger
  - Same size, except for length of auger housing.
  - Length decreased for ease of testing.



TESTING PROCEDURES

- To collect our data we will fill our hopper with proppant and start the auger and let it run until it reaches the desired speed.
- Once the auger has reached the desired speed, we will start the auger feeding into a second bin and start a timer.
- After the test is finished we will take the proppant that the auger moved during the timed interval and measure the weight of material.
- The weight of the proppant moved and the time interval will be used to calculate pounds per minute.
- This procedure we be ran on each design prototype and at multiple speeds.

SPECULATIVE PROTOTYPE DATA



CONCLUSION

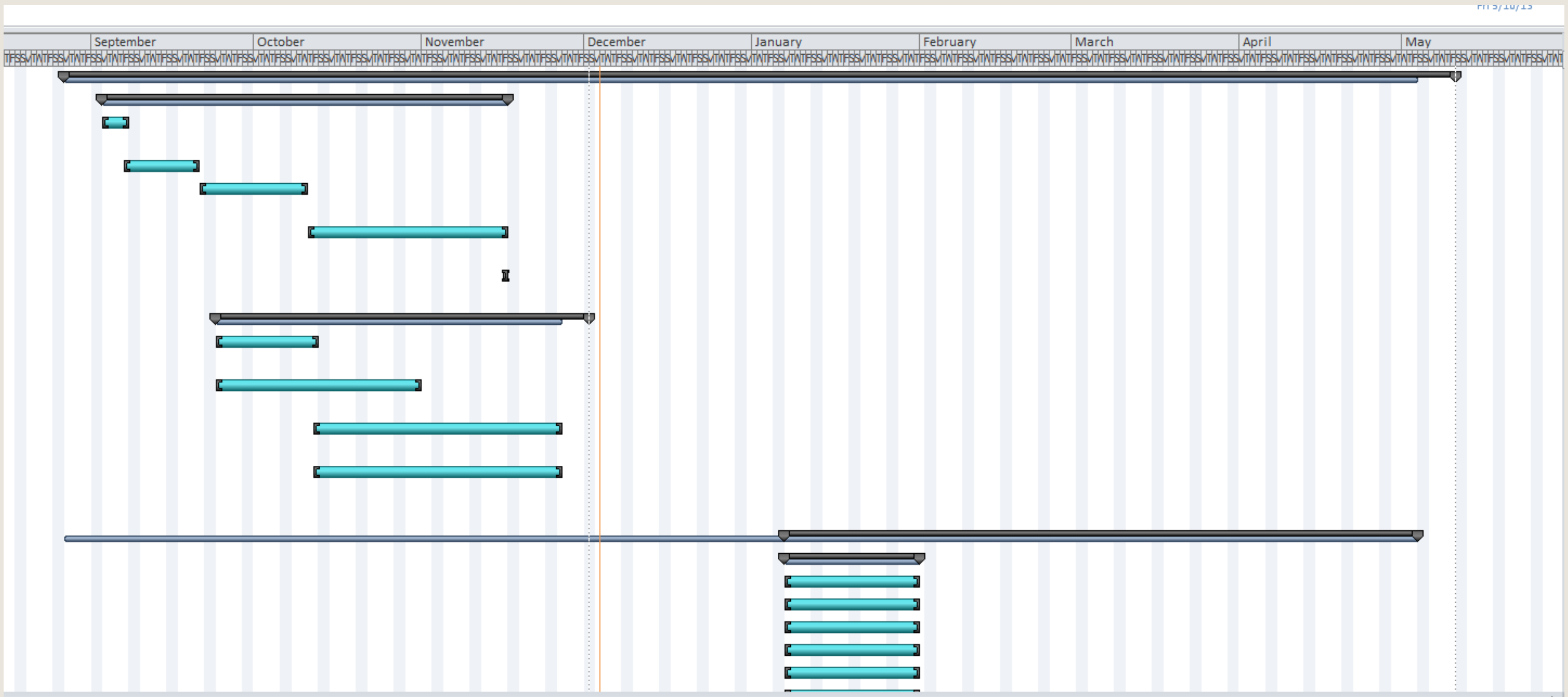
- Our deliverables have all been achieved for this semester.
- We will begin prototype planning once all our designs have been approved.
- The prototype will be built and tested in the spring semester.

SCHEDULE

Task Name	Duration	Start	Finish
Optimize Auger Output	**185 days**	**Mon 8/27/12**	**Fri 5/10/13**
Produce Equation	**55 days**	**Mon 9/3/12**	**Fri 11/16/12**
Get test data from Halliburton	5 days	Mon 9/3/12	Fri 9/7/12
Analyze data in excel	10 days	Fri 9/7/12	Thu 9/20/12
Analyze data in TableCurve	14 days	Fri 9/21/12	Wed 10/10/12
Evaluate TableCurve equations	27 days	Thu 10/11/12	Fri 11/16/12
Choose best equation	1 day	Fri 11/16/12	Fri 11/16/12
Redesign equipment	**51 days**	**Mon 9/24/12**	**Sat 12/1/12**
Make SolidWorks drawing of 6" auger	15 days	Mon 9/24/12	Fri 10/12/12
Analyze current design shaft stresses	28 days	Mon 9/24/12	Wed 10/31/12
Generate redesign options	32 days	Fri 10/12/12	Mon 11/26/12
Choose best design options for prototypes	32 days	Fri 10/12/12	Mon 11/26/12
Prototype Testing	**85 days**	**Mon 1/7/13**	**Fri 5/3/13**
Acquire Equipment	**19 days**	**Mon 1/7/13**	**Thu 1/31/13**
Auger shafts	19 days	Mon 1/7/13	Thu 1/31/13
auger flighting	19 days	Mon 1/7/13	Thu 1/31/13
Auger bearings	19 days	Mon 1/7/13	Thu 1/31/13
auger housing	19 days	Mon 1/7/13	Thu 1/31/13
hoppers	19 days	Mon 1/7/13	Thu 1/31/13
variable speed drive and power source	19 days	Mon 1/7/13	Thu 1/31/13
proppant	19 days	Mon 1/7/13	Thu 1/31/13
Test stand	19 days	Mon 1/7/13	Thu 1/31/13
test site	19 days	Mon 1/7/13	Thu 1/31/13

Task Name	Duration	Start	Finish
Testing	**75 days**	**Mon 1/7/13**	**Fri 4/19/13**
Set up equipment	19 days	Mon 1/7/13	Thu 1/31/13
run control test	13 days	Thu 1/31/13	Sat 2/16/13
change variables	37 days	Sat 2/16/13	Sun 4/7/13
repeat test	46 days	Sat 2/16/13	Fri 4/19/13
Results	**67 days**	**Thu 1/31/13**	**Fri 5/3/13**
analyze test results	67 days	Thu 1/31/13	Fri 5/3/13
produce equation that describes new prototype output	67 days	Thu 1/31/13	Fri 5/3/13
compare prototype equation with current design equation	67 days	Thu 1/31/13	Fri 5/3/13
Report	**180 days**	**Mon 8/27/12**	**Fri 5/3/13**
Written report	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	10 days	Mon 8/27/12	Fri 9/7/12
write first draft	66 days	Mon 8/27/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize report	2 days	Mon 12/3/12	Tue 12/4/12
powerpoint	**71 days**	**Mon 8/27/12**	**Mon 12/3/12**
select outline	35 days	Mon 8/27/12	Fri 10/12/12
create first draft	32 days	Fri 10/12/12	Mon 11/26/12
edit first draft	6 days	Mon 11/26/12	Mon 12/3/12
finalize presentation	2 days	Mon 12/3/12	Tue 12/4/12
Oral Presentation	**3 days**	**Mon 12/3/12**	**Wed 12/5/12**
practice presentation	1 day	Tue 12/4/12	Tue 12/4/12
present final report	1 day	Wed 12/5/12	Wed 12/5/12

SCHEDULE


September
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May

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QUESTIONS?