With respect to the University of Vermont College of Engineering and Mathematical Sciences:

The intent of this report is to present the design, analysis, prototype realization and test of a hops baler for the Hops Baler 2.0 project. The work presented here was performed as a two-semester long project as a part of the UVM School of Engineering's C

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With respect to the University of Vermont Extension:

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To: Dr. Heather Darby
Rosalie Madden

In our report, there are detailed description and analyses of all parts of the Hops Baler 2.0 Project. We clarify the objectives and constraints to show we have met all the requirements you were looking for. We have designed and built our machine to the best of our abilities and are glad you approve of our work. We cannot thank you enough, Heather and Rosalie, for the opportunity and support throughout the yearts W 3-11(y)20(6j)6iieeh4(nd)l1.(the)-892t87(3-11(y)2the)-67(in Mike Rosen constantly d to better our project. We ve rned much throughout the whole prt and not have been able to if it were not for our sponsors UVM Extension, SEED, and College Engineering and themaica S es. We re 0(6j)6iiefunded inie part by the Vermont Agricultural Innovation Center through the United St2t874(s)-10( )]T

Senator Patrick Leay. We could not have done it without all these great people and programs.

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Problem Statement

Vermont and other Northeastern states have seen resurgence in hops production. The demand for locally produced foods has spurred an interest by microbreweries to search out local hops. The small acreage of Northeastern hop farms requires scalable production and processing infrastructure. The available hops balers are aimed at major producers that construct a 200 lb bale. Our team will develop an alternative design, aimed at producing 5-10 lb bales using human power, with a particular emphasis on preserving quality, safety, low cost and time efficiency.

Design Overview

The design uses human power with a mechanical advantage to supply an uncompressed volume of hops with a load large enough to compress them down to a small, compact bale. The initial volume of hops is determined by a value for the initial density, which was found through test trials in the materials testing laboratory. The density of hops varies depending on how long they have been drying, hop variety, and level of compaction prior to entering the baler. With this in mind, an initial density value was chosen that took all of those aspects into consideration.

A final Solidworks model of our design can be seen in Figure 1. The design and subsystems will be explained in detail in the Design Details section of this report.

Figure 1. Final Solidworks model for Baler 2.0.

Objective Analysis

Through an aggregate rank ordering, four basic objectives were determined for the hops baler, as seen below in the objective tree. We determined that the baler needed to be scalable to produce bales from 5 to 10 pounds, that it needed to be automated in the sense that a continuous flow could be established, it needed to be safe i.e. no exposed sharp edges and no risk of getting caught in moving parts, and most importantly it needed to be marketable. In order to determine how well our final design will fulfill each of these objectives, we constructed a metrics chart and used projected values for each objective to determine a final performance score of our design.

Figure 2. Metrics chart used to determine final performance score for Baler 2.0.

Our device has met all the objectives besides automation, safety guards and lightweight. When we were initially listing objectives we thought our baler would be powered pneumatically or by electricity, but after testing we determined that all power requirements could be satiated

Function Analysis

To perform a function analysis we mapped out the flow of inputs, sub-functions, and means in a function-means tree. This provided us with an excellent organized graphic of the required steps involved in manufacturing a hops bale, and the required inputs and means that would be needed to accomplish these steps and at what point these inputs needed to be introduced. This helped us look at individual steps and discuss all possible methods of accomplishing each, and ultimately which method we felt was the best.

Requirements:

In order to complete the task of forming a hops bale of a given size, we determined four requirements that the hops baler design needed to have. The design needed some method of packaging and maintaining hop quality, an adequate mechanical power source input, a method of adding hops efficiently, and a well designed compression system to actually press the hops into a bale. Through a brainstorming session we found several means of accomplishing each requirement in order to allow for a broad range of design ideas which we could later narrow down based on a ranking system as well as experimentation.

Function	Requirement
Unite Hops to Bag	No Loss of Hops

Actual Metric:

	Best Case (BC)	**Worst Acceptable (WA)**	**Estimated Actual (A*)**	**W***
Bale Size (lb)	10	1	5	0.444444444
Machine Weight (lb)	100	300	225	

Design Details

Frame:

Figure 3 shows the frame portion of the design. It is made entirely of 5/4" wide by 3/16" thick square angle iron stock. The frame dimensions are 2' by 2' by 5', and all the pieces are welded together.

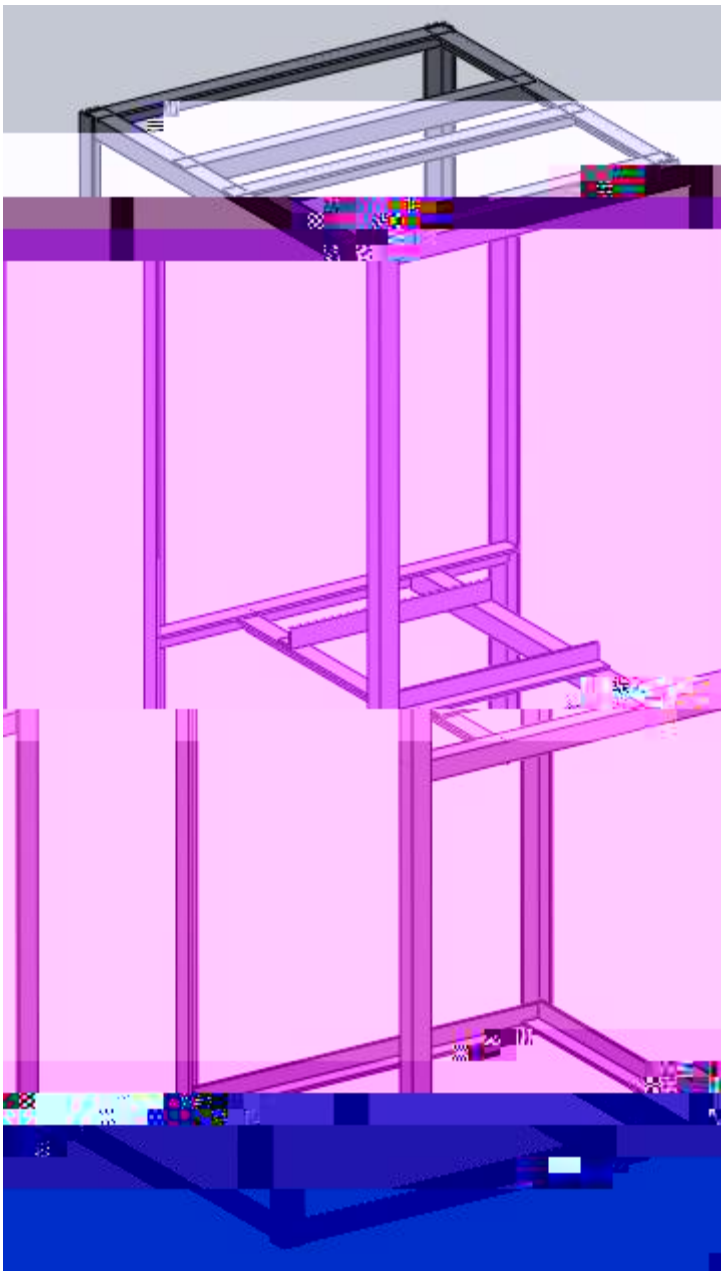

Figure 3. Baler 2.0 frame.

Funnel:

Figure 4 shows the funnel component of the design. The funnel walls are made of high density polyethylene, chosen for its low friction value, which is held together by aluminum angle stock fastened with self-tapping screws. The polyethylene

Gear Assembly:

Figure 5. Gear assembly for Baler 2.0.

The gear assembly (Figure 5) transmits the force applied on the crank wheel to the rack and thereby to the plunger. The crank wheel is fixed to a keyed input shaft, which is fixed by three cast iron mounted bearings and also holds the first input gear. The shaft is 30” long and has a diameter of ¾”. It is fully keyed with a 3/16” by 3/32" keyway. The input gear has a diameter of 5.125”, a 20º pressure angle, a pitch of 16, and a face width of ¾”. The force from

Plunger:

Figure 6. Plunger component for Baler 2.0.

The plunger component (Figure 6) consists of a flat plate base made of ¼" thick steel with guide plates welded onto the top of the plate to prevent it from becoming misaligned with the funnel and form box. Welded onto the plate is our rack, which receives the power input and delivers it to the hops. The rack is 5' tall and has pitch of 16 with a 20º pressure angle and is a ¾ in². The rack is braced by four angled pieces of plate steel, which are welded to both the rack and the plunger plate. Several small holes have been drilled into the plate and small pieces of thin rubber have been epoxied over them to act as one-

Shaper Box:

Figure 8. Baler 2.0 shaper box.

Our bale shaper box (Figure 8

Figure 11

Stress testing of the frame:

Figure 12. Simulated stress test results on frame.

From the testing done in the lab, and from our calculations which can be seen above, we conducted simulation testing on the necessary components of our design. In Figure 12, a simulation on the frame was conducted where a 757lb load was applied to one side (which is an extreme case since the load will be distributed between the two sides.) The stress plot shown to the right demonstrates that the maximum stress felt by the frame is well below the yield strength of our frame material.

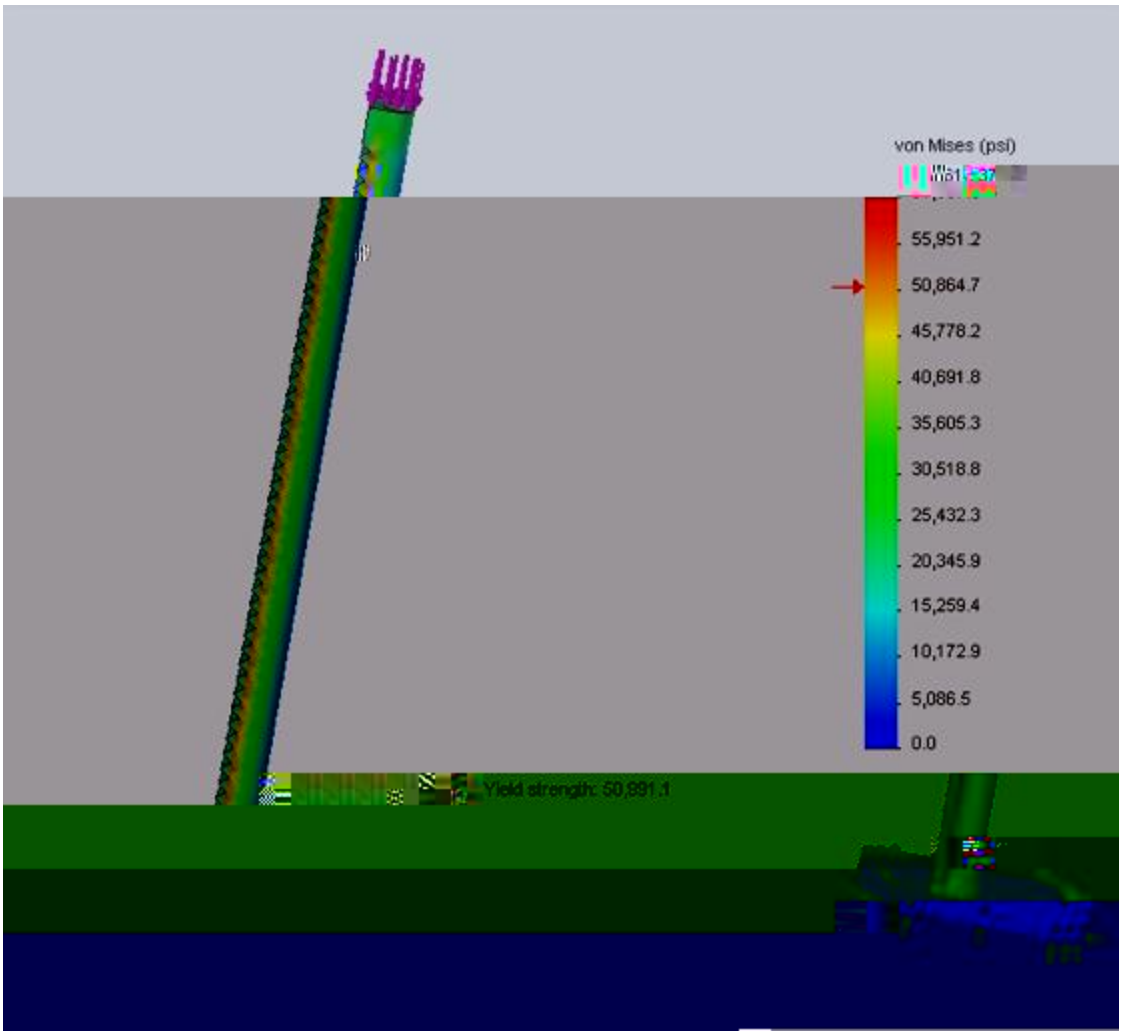

Figure 13. Simulated stress test results on plunger.

Figure 13 shows the plunger apparatus fixed at the bottom face with a load on the top of 70000lbf, which created failure. This analysis tells us that the plunger can withstand a load slightly less than 70000lbf, which again is well above what we expect the plunger will have to endure.

Analysis

Weight of hops: 5 lb
Density of loose hops: 2.5 lb/ft³
Density of compressed hops: 9 lb/ft³
Cross sectional area of funnel/shaper box: 0.694 ft²
Maximum output force: 757 lb
Maximum input force: 50 lb
Diameter of crank wheel: 36 in
La[ )]TJET EMC /P ‹(ft³)]TJETBT1 0 0 1 224‹(f0]T 0 1 224 /P ‹0)7[.125ET EMC /P ‹MCID 9/L17DC t³)]TJE

Conclusions

By using only human power and a mechanical advantage of a 17:1 gear transmission, a 5lb bale can be compressed to the threshold density of 9lbs/ft^3. The transverse stress that develops as a result of the vertical compression on the hops is almost negligible, and design considerations for this stress are minimal. After conducting multiple trials, it is clear that the rebound of the hops after compression is small and does not interfere with bagging.

After testing, only a couple of open issues stand out. When testing, we were only able to procure 2 year old dried up hops, which behave differently than freshly cut hops off the vine. Fresh hops secrete a resin when crushed that could potentially clog the one way air valves.

Budget

Preliminary Estimated Budget:

Heat Sealer/Slicer: Impulse by U-line	$215
Frame: Twelve 6’ 90º angle steel	$180
Plunger Rod: 5’ hollow 1’ outside diameter tube	$150
Funnel Head/Pipe: Two 4’x4’ sheet polyetheline	$80
Piston Head: 1’x1’ stainless steel plate	$75
Bagging: 16”x400’ heavy duty plastic tubing	$60
Gears: Three steel plain-bore pressure angle spur gear	$45
Bearings: Three ⅛” lubricated steel	$30
Drive shaft: 4’ solid steel bar	$20
Wood: Lazy susan and shaper blocks	$10
Piston Head Gasket: Polyethylene rubber	$7
Total	**$872**

Actual Budget:

Quantity	Item and Supplier

Schedule

Figure 14. Preliminary Gantt chart.

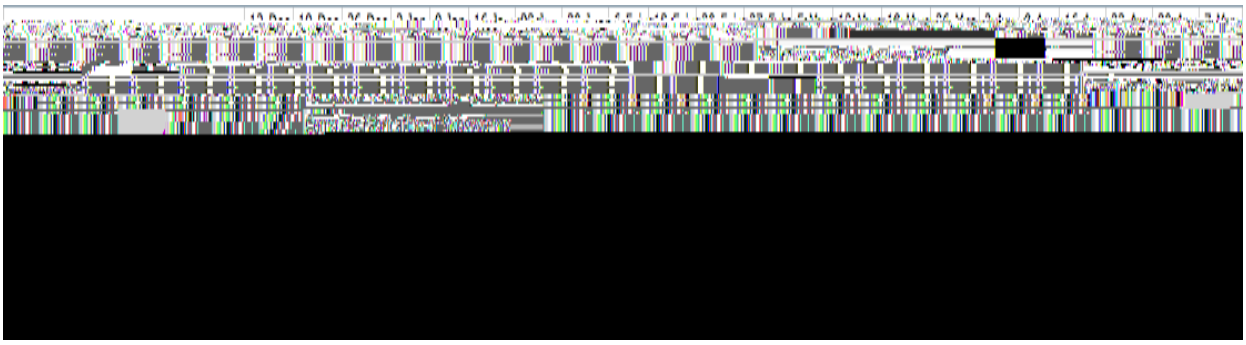

Figure 15. Final Gantt chart.

Our preliminary Gantt chart had us completing many parts of our project before the actual completion of them. We finished many of our features later than expected due to complications during the building process and the high demand for machine shop time. We also had our crank wheel come in a week later than expected when it was already arriving late in the building process. All in all, the entire build took more time and effort than expected.

Test Plans

Once we completed the hops baler, we tested it in outside conditions. We went through the whole process from attaching the bag and pouring hops in to compressing the bale and removing from the shaper box. The process from start to finished bale takes about 2 minutes. We were unable to use the vacuum sealer for our final step because our clients possess it. Instead we folded the excess bag neatly and duct taped it, which proved to help the bale withhold its shape for a few hours. If the bale is properly heat sealed then it will hold its shape as long as the bag is not punctured.

We also allowed some select guests at the University of Vermont's design night to spin the crank wheel and feel the max force at the end of the stroke. Observing their cranking styles and the machine stability has proven that the baler is quite balanced and has no reason to tip or slide.

For a YouTube video of the baler in action, please visit: