DESIGN, CONSTRUCTION, AND EVALUATION OF A HYDRAULIC OIL FILTRATION CART

by

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ABSTRACT

This report discusses the design, construction, and evaluation of a hydraulic oil filtration cart sponsored by Papich Construction Inc. This company developed the need for a filter cart system to service equipment by flushing and cleaning the oil in hydraulic reservoirs and systems. The opportunity of reviewing an existing product from Caterpillar was taken to obtain basic design parameters. This cart however, did not meet all the needs preferred by the service technicians of Papich; thus leading to the idea of a custom filter cart.

The filter cart is composed of a square tube frame sitting on pneumatic no-flat castor wheels, and features a 28-gallon oil reservoir with black pipe plumbing through six Caterpillar filters in series. Hydraulic oil can be pumped from either a suction hose or the cart’s reservoir and through the filter series by way of a pneumatic diaphragm pump. The design of this cart allows service technicians to easily transport, operate and maintain its components.
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INTRODUCTION

Construction of modern amenities for societal transit such as roads, bridges, and the installation of underground utilities require the use of engineering, manpower, and specialized equipment. Such equipment used to accomplish these tasks range in size and technology; yet they all have a fundamental similarity. Machines used in this line of work all rely on hydraulics, in some way, to accomplish the demanding tasks that allow for many of our modern luxuries in developed environments. Surrounding conditions of these machines when operating are, to say the least, less than tranquil. Hydraulic systems are constantly threatened by contaminates in the form of debris that can enter the hydraulic system through the reservoir, a cylinder, or hose. Debris can also be introduced internally when a component such as a hydraulic motor or pump fails, sending its own material throughout the system. Hydraulic oil filters are designed into the system as a crucial protector, yet they may not be enough in some cases to keep the oil clean. Debris in any hydraulic system can cause costly damage to components that have tight tolerances and potentially lead to their failure.

Papich Construction Incorporated is one such company with services that build roads, bridges, and install underground utilities. They have a large fleet of equipment, the majority of which utilize hydraulics to accomplish work. This company developed the need for a machine capable of filtering contaminated oil while keeping the oil in the hydraulic system rather than replacing it. Products are available today that act in much the same way as dialysis machines for humans. They come in all sizes, from carts to whole trucks dedicated to externally filtering hydraulic oil using a pump and filters. There were a couple of products that seemed to fit one requirement or another, yet not one had everything the sponsor was seeking.

After interviewing with the Equipment Manager and Lead Mechanic of Papich, objectives were identified and currently offered products with similar purpose were reviewed, resulting in the initial designs for a custom hydraulic oil filtration cart. A major requirement for Papich was the cart had to fit in the back of any of their service trucks while giving the mechanic the option of using the onboard crane or a forklift to load it. With functionality in mind, it was recommended that a reservoir be added for optional fluid storage to introduce or reclaim oil from the hydraulic system in service. All filter heads had to be synonymous for the option of either using all the same micron size or using a variety of micron sizes and stepping the process from large micron to small micron. Adapters were made to allow for the inlet hose to tap into transmission cooler lines or to plumb into an oil reservoir.

Preliminary cost estimates indicated that building a custom filtration cart would be under what similar machines cost while having benefits tailored to Papich Construction’s specifications. The decision was made by the owner, Jason Papich, to go ahead with the project. Contacts for advice to aid in the development of constraints and objectives were obtained immediately and initial concepts were drafted.
All metal material was purchased through B & B Steel Supply in Santa Maria, CA. The pump was selected using constraints from the sponsor and through market research on current model filter carts, then purchased locally through JB Dewar. Filters and the filter heads were selected for their versatility in accepting several filters that nominally range in micron size from 2, 5, 10, and 25 micron; they were purchased through Quinn-Cat Rental of Santa Maria, CA.

The goal of this senior project was to design, construct, and test the machine outlined above. Once complete, it was tested on equipment belonging to Papich Construction with oil samples sent out to a lab for analysis to evaluate cleanliness performance. The following lists of constraints were considered during design and fabrication.

1. Ability to add and remove oil to a hydraulic system.
2. Encapsulated, symmetrical design with a low center of gravity.
3. Filter oil of high particle count to achieve a lesser particle count.
4. Must fit in the back of a service truck that has space 4’ wide and 6’ long.

Figure 1. Papich service truck.
LITERATURE REVIEW

Similar Products.

The Quinn division of Caterpillar, located in the City of Industry, CA, has developed a filtration cart that is designed to filter a large volume of oil. It is comprised of five filters with a pneumatic diaphragm pump that pulls fluid from a reservoir on the equipment, filters the oil, and returns it to the reservoir. The cost of this machine before taxes totaled $9,262. It is about 700 pounds sitting on three wheels with a storage box for extra filters and parts; this cart does not have a reservoir and is suitably unfit for hoisting due to its unsymmetrical shape (Jewett, 2012).

![Figure 2. Quinn-Cat filter cart.](image)

The Parker Hannifin Corporation has been manufacturing products in the hydraulic systems industry since 1918. This company makes a comparable filtration cart to the Quinn Company’s yet with some distinct differences. Parker’s cart uses two high-volume filters that can filter the same amount of fluid as Quinn’s. Yet Parker’s cart is different because its filtering elements contain Par-Gel elements, which effectively remove water from the oil (Parker, 2009). In addition to the same downfalls as the Quinn cart, this cart has an electric pump which is unfavorable for service operations on the job site.

![Figure 3. Parker Hannifin filter cart (Parker, 2009).](image)
Cleanliness Standards.

Hydraulic oil usually has some form of contamination, even when it is new. Contaminate size is measured in units called “microns.” Depending on the type of hydraulic system, a certain level of oil cleanliness is required. For example, as seen in Figure 4, a servo hydraulic system typically used on precision equipment requires an ISO level 14/11. The first number in the ISO code is the amount of particles per milliliter that are greater than 6µm and the second number is the amount of particles per milliliter that are greater than 14µm (Polaris, 2004). Any results that indicate higher numbers than the code given for the specific hydraulic system would indicate an inefficient filtering process. Hydraulic filters are rated on the size of particle, in microns, that they can efficiently remove. There are two ways to measure filter efficiency; beta ratio ($\beta$) or particle size ($\chi$). Given a specific size of particle, beta ratio is measured by the number of particles that enter a filter divided by the number of particles that exit the filter. As seen in Figure 5, the greater the beta ratio, the greater the percent of efficiency. The beta ratio is the most effective way to evaluate the efficiency of a filter (Casey, 2004).

Table 1. ISO cleanliness level for different hydraulic systems (Casey, 2004).

<table>
<thead>
<tr>
<th>Type of Hydraulic System</th>
<th>Minimum Recommended Cleanliness Level</th>
<th>Minimum Recommended Filtration Level in Microns ($\beta_2 \geq 100$)</th>
</tr>
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<tr>
<td></td>
<td>ISO 4406</td>
<td>NAS 1633*</td>
</tr>
<tr>
<td>High pressure (250 to 400 bar)</td>
<td>15/12</td>
<td>6</td>
</tr>
<tr>
<td>Medium pressure (50 to 150 bar)</td>
<td>18/15</td>
<td>9</td>
</tr>
<tr>
<td>Low pressure (&lt; 50 bar)</td>
<td>19/16</td>
<td>10</td>
</tr>
<tr>
<td>Large clearance</td>
<td>21/18</td>
<td>12</td>
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Table 2. Beta ratios and corresponding efficiencies (Casey, 2004).

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<th>Filter Beta Ratio and Percentage Equivalents</th>
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<tbody>
<tr>
<td>$\beta$</td>
</tr>
<tr>
<td>2.0</td>
</tr>
<tr>
<td>2.4</td>
</tr>
<tr>
<td>3.0</td>
</tr>
<tr>
<td>4.0</td>
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Filters.

The filters that were selected for the initial test of the machine are Caterpillar 10 micron hydraulic filters. Options were discussed with the Equipment Manager at Papich, and these filters were chosen for their price point along with the understanding of a baseline test as compared to varying the filter series from coarse to fine particle size at a later time. The Cat 9U-5870 hydraulic oil filters are made with a synthetic filter element rather than paper and are considered to be advanced efficiency. There are three efficiency
standards that Cat offers with their filter lines; standard efficiency, advanced efficiency, and ultra-high efficiency (UHE). Cat recommends that UHE filters be used on a hydraulic system for 250 hours after a rebuild, maintenance, or the intrusion of contaminants into the system (Caterpillar, 2010). The filter heads chosen for this project are compatible with all three filter choices. This way, in the future Papich Construction can use cheaper yet effective filters for older equipment or use the UHE filters for newer equipment with tighter tolerances. Figure 6 graphically illustrates the efficiency versus micron size for each of Cat’s offered filter choices.

Figure 6 Graphically illustrates the efficiency versus micron size for each of Cat’s offered filter choices.

Caterpillar filters are produced with a synthetic element that induces a lesser pressure drop than filters without synthetic elements. These filters also reduce oil bypass during cold starts which causes less wear to hydraulic system components (Caterpillar, 2010). The 10 micron filter used on the cart for its initial test has a beta ratio of 1000. This means that the amount of particles entering the filter as compared to exiting the filter is cut down by 99.9% (Hydrafil, 2012). Figure 5 gives a comparison between Cat filters with synthetic elements versus other filters with paper-type elements.

Figure 5 Graphical comparison of Cat UHE filters to off-brand filters (Caterpillar, 2010).
**PROCEDURES AND METHODS**

**Design Procedure**

**Main Frame.** The main frame of the hydraulic filtration cart is designed around a concept of centered weight. An objective of the project and constraint assigned by the sponsor is to have the ability to hoist it with a crane located on the service truck or place it in the truck using a forklift. Other filter cart models observed were asymmetrically designed, causing the machine to list one way or another when hoisted or lifted. The frame of this project is symmetrically designed with the components installed close to the middle and the majority of the weight located in the bottom half of the machine. This design is meant to keep the unit stable when hoisted or lifted into the back of the service truck and for stability when moved across a jobsite or shop floor.

The design also keeps friendly the idea of maintenance; the pump mount and filter bracket are removable, and the reservoir can be removed out from the bottom of the cart. This is due to its mounting configuration between two brackets welded to the inside of the bottom of the frame. These brackets are each one piece with two mounting planes; horizontal for the castors to bolt to and vertical for the threaded reservoir mounting slugs to bolt to (figure 6). The pump is mounted on a separate mount that bolts to the frame through isolating rubber with four 7/16” bolts on each corner of the mount. The plumbed filters are supported by the pump, the reservoir and a bracket that is wide enough for the length of the four-gang filter assembly to bolt to; this bracket bears the majority of the weight of the plumbing system (figures 8 and 9).

Materials used for the frame include:
- 1 ½” square tube
- 10 gage sheet metal
- Two swivel castors
- Two fixed castors
- 1” x 2” channel
- 1” square stock
- Twelve ¾” fasteners
- Four 7/16” fasteners

![Figure 6. Reservoir and caster mounting bracket.](image-url)
Figure 7. Drawing of cart frame skeleton.

Figure 8. Isometric draft of filter bracket.

Figure 9. CAD drawing of filter bracket.
Fluid Transfer. The basic design of the fluid mechanics for this machine was based off the objectives determined from discussion with the sponsor. A dual-diaphragm pneumatic pump was selected for its durability to handle oil with particulate contaminates suspended in it. The pump is plumbed to a 28-gallon reservoir with a three-way diverting valve that gives the operator a choice between pulling oil from a hydraulic system through the suction line or pulling oil from the cart’s reservoir. The oil in this reservoir can be used to add oil to the system or if there is a need to prime the filtering system. Once the pump is operating, the fluid transfer will be selected from one of the two options. The oil flows from the inlet to the pump and is pushed through six filters by way of black pipe plumbing. There are two pressure gauges in the system and one flow indicator. The first pressure gauge is located at the first filter and the second is located at the sixth filter. There is a flow indicator that shows only red or green colors based on the presence of flow. On the outlet side of the system is a second three-way diverting valve which allows flow to either an outlet hose or back to reservoir. There are union joints placed in the suction and return pipes plumbed to the reservoir as well as a union just after the outlet of the pump. These unions allow components of the machine to be removed and replaced easily in the case of maintenance or repair needs.

Fluid Filtration. The filter heads used for this project were chosen from Caterpillar and are cast aluminum with 1 ½” NPT ports. One four-filter manifold unit was designed by Caterpillar to have the four filters in parallel so the filtering area is quadrupled. It was plumbed in series between two single filter head units to maintain symmetry in the plumbing design and bring the total filter count to six. Filters compatible with these heads vary from as fine as 2 micron to as coarse as 149 micron; allowing for the option to either vary the filters from high to low micron or maintain a constant micron size throughout the series. For the build and initial running of the cart, the sponsor has chosen to use a consistent series of 10-micron filters capable of holding 64 grams of dirt each (table 1).
Instruments & Control. To adjust pump speed, an air filter regulator with a male air fitting and air pressure gauge is plumbed into the pump. The air regulator has a maximum allowable pressure of 125 psi, the same rated maximum as the pump. By regulating the amount of air entering the pump, the speed at which the pump cycles can be adjusted. The two pressure gauges in the system allow for monitoring of pressure at the beginning and end of the circuit. They also effectively read the pressure drop across the four-filter manifold. Other control features of the cart include the two three-way diverting valves that allow for the control of flow from reservoir or flow from the hose. There are plugged testing ports throughout the system; two on each of the single filter heads and one on the four-filter manifold. These ports can be used to install test fittings for pulling oil samples, or for adding another gauge.

Construction Procedure

Main Frame. The main frame of the cart was constructed first, using 1 ½” x 1 ½” x 3/16” square tube. Six lengths were cut at 48” and six cut at 36” with opposing 45° mitered cuts on each end. The pieces were welded in the fashion that formed three 48” by 36” rectangles. Once those rectangles were fabricated, four pieces of the same size square tube were cut at 5” and four at 30”. The three rectangles were welded together in the same horizontal plane using the four 5” pieces in the vertical plane on each corner separating the bottom two rectangles. The 30” pieces were welded in the same fashion creating a cube shape with three levels. The bracket was drawn on AutoCAD and two of them were cut out from 10-gage sheet metal on an automated plasma cutter. The two brackets were later bent using a press brake so that a 1 ½” vertical plane was created for the reservoir to mount to. These brackets were welded on the inside of the square tube at
the bottom of the frame and run the length of the frame. These brackets were designed with 4” by 4½” pads in each corner for the four no-flat pneumatic tires to mount; two casters with brakes and two fixed without brakes. The broke vertical plane of the bracket was designed with a wide enough surface to become a mounting flange for the reservoir.

The four-gang filter bracket that supports a portion of the filtering system was fabricated out of a piece of 10-gage sheet metal that had been left over after the reservoir was cut out. It the shape was traced out with an awl and it was cut using the flywheel shear in Shop 6. The angled edges of the bracket were bent to 90° using the press brake in Shop 6. To mount the bracket on the cart frame two 1” strips of 10-gage were cut and welded to the inside of the vertical edges of the bracket. This created a mounting surface perpendicular to the side of the bracket to allow for bolting to the frame. To mount the pump to the cart frame, a cross member was fabricated using two pieces of 1” x 2” channel and welding three 1” square tube braces in between them. This mount is isolated from the cart frame with cut pieces of conveyor belt rubber that are stacked together and drilled through for the bolt. Each of the four rubber cubes fit inside a corner of the channel and keeps the mount 1/8” off the cart frame.

Four no-flat pneumatic caster wheels were used to allow for ease of movement across a shop floor with air hoses, etcetera; and out in the field. Two casters on one end of the cart are fixed while the two on the opposite end swivel and are equipped with friction brakes. These casters have a mounting pad of just under 4” by 4 ½” which is one reason for the fabricated brackets. They are fastened to the bottom of the bracket using four 3/8” bolts and nuts per caster.

![Figure 12. Pump mounting holes and installation.](image-url)
Figure 13. Pump mount with isolators.

Figure 14. Caster and reservoir mounting bracket.
Fluid Storage. The reservoir was designed to fit inside the cart between the two brackets so it can be removed out the bottom of the cart without disrupting the plumbing. The reservoir is made from 10-gage sheet metal that was cut on the PlasmaCam resulting in two pieces that were bent, using the press brake, on opposite edges. This allowed the two pieces to be inverted and fitted together requiring welding on only eight edges rather twelve. The reservoir is 44” long by 21” wide; capable of storing 28-gallons of oil. There is an access hole cut out at one end of the reservoir to allow for easy cleaning and easing troubleshooting efforts. This is sealed using a cover with a gasket and 14, 3/8” bolts. The filler cap is vented with an internal strainer and a ¾” drain with a magnetic plug on the bottom of the reservoir allowing it to be filled or drained without use of the pump. To mount the filler cap a 2” hole-saw was used and six holes were drilled and tapped to accept ¼” machine screws. For the reservoir to mount on the bottom of the cart yet still have the ability to be removed out the bottom, eight slugs were milled to the same height of 1” from hexagonal solid stock 1 ½” in diameter. These were drilled and tapped to accept 7/16” bolts and welded to the outside of the reservoir with four per side. These slugs fasten the reservoir to the brackets by placing the bolts in shear.
Figure 16. Prepared reservoir pieces.

Figure 17. Fitted reservoir pieces (pre-welding).
Figure 18. Fully welded reservoir.

Figure 19. Tapping the fill cap mounting holes.
Figure 20. Installed filler cap.

Figure 21. Gasket material used for access cover.
Figure 22. ¾” reservoir drain.

Figure 23. Slugs mounting reservoir to cart.
Figure 24. Reservoir mounted in cart frame (bottom view).

Figure 25. Reservoir mounted in cart frame (top view).
**Fluid Transfer.** The plumbing medium chosen for this project was 1 ½” black pipe fitted together using soft pipe sealant as specified by the sponsor. The filters were plumbed to the pump using black pipe nipples at various lengths. Plumbing the system to the reservoir required custom lengths that were cut with the band saw and threaded using the large NPT pipe tap located in Shop 6. The pipes plumbed to the reservoir aid in supporting some of the weight of the filters and pipes, yet more support was needed. A bracket mentioned in the previous section is used to relieve the majority of the weight strain from the plumbing and joints. A 2” hole-saw was used to cut two holes in the top of the reservoir that weld-in NPT bungs were welded into for an oil pickup and return. The reservoir was pressure tested using air in company with soapy water to check for leaks. The pickup was then fabricated and consists of a piece of pipe welded into 2” NPT male to 1 ½” NPT female adapter. This pickup sits approximately ½” off the bottom of the reservoir and is plumbed to the three-way diverter valve via a 2” nipple. After the valve the oil is pumped through a union joint, around an elbow and through the first filter.

Ratchet straps and lifting slings were used with C-clamps to position the filter heads. Vice grips were used to temporarily mount the pump for measurements of the oil pickup pipe hole. Once the orifices of the filter heads were level with the outlet of the pump (top of pump), various nipple sizes and 90° elbows were used to mock up the plumbing system. After the hole was cut and the bung welded in for the reservoir pick-up, the pump was adjusted to its final position; dictated by the three-way diverting valve and plumbing in between the pump inlet and reservoir pick-up.

![Figure 26. Mock-up of filter-process components.](image-url)
Figure 27. Determining plumbing layout.

Figure 28. Alignment of reservoir pick-up to pump.
Figure 29. Valve and 1st filter head plumbed.

Figure 30. Four-filter manifold mounted to bracket.
Figure 31. Width of plumbing system.
Figure 32. Mock up for return piping.
Figure 33. Cutting threads for return pipe.

Figure 34. Suction fitting complete.
Figure 35. Return fitting complete.

Figure 36. Side view of completed plumbing system.
Figure 37. Completed cart view #1.

Figure 38. Completed cart view #2.
Figure 39. Completed cart view #3.

Figure 40. Completed cart view #4.
Testing Procedure

Before the cart could be tested on a piece of equipment’s hydraulic system, the reservoir had to be pressure tested for any leaks. To do this a male air fitting was fitted to a ¾” female NPT to 1 ½” male NPT increaser that screwed into the bung of the reservoir meant for the pickup pipe. Using a regulator and shop air supply, the reservoir was filled with air to approximately 3 psi and a mixture of soap and water was applied to all welded portions of the reservoir. Any areas where bubbles appeared were dried off, cleaned up with the grinder and had another weld bead applied. This process continued until there were no more leaks. The pressure was increased to a maximum of 5 psi and double checked with soapy water to ensure a complete seal.

Once the cart was plumbed and all the bolts tightened for the final time, it was taken to Papich Construction’s fleet shop on Sheridan Rd. in Nipomo, CA. At the shop they had a 2008 International street sweeper truck that had contamination in the hydraulic system. There was a hydraulic pump that failed and caused metal shavings to disperse through all the lines. This is a perfect candidate for the filter cart application because it contains several moving components that are all hydraulically operated. The filter cart was plumbed into the hydraulic system of the street sweeper where the failed pump had been. The suction hose of the cart was connected to the supply hose of the truck that oil would normally be drawn from by the hydraulic pump. The return side of the cart was plumbed into the pressure side of the truck’s hydraulic system.

When the pump on the cart was activated by air pressure, there was a two second delay until the pump primed and began moving oil. The pump audibly sounded primed and the first gauge had a reading; when the second gauge began to register it was clear the system was filled. The operating pressure was set at 20 psi and left alone to cycle for about four hours. One hour into the testing, as a mechanic was working on the main sweeping barrel and ended up tripping a safety switch that ended up blocking the flow in the system. The mechanic could not get the issue resolved before the day was out, although samples of the oil were still pulled for testing.
Figure 41. Pressure testing the reservoir.

Figure 42. 2008 International Allianz-Johnston MT350.
Figure 43. Suction and return connections.

Figure 44. Supply line connections.
Figure 45. Testing setup view #1.

Figure 46. Testing setup view #2.
As an introduction of the machine to a group of mechanics, it was given a second trial run using contaminated oil from a waste-oil collection bin. The demonstration lasted an hour with half of that hour using the cart to filter approximately ten gallons of contaminated oil from a 1970 Caterpillar 631 Scraper that had been drained into the collection bin. Pressures were observed for the low-resistance scenario to compare against the first test. Methods of operation were explained and reviewed as the cart cycled the oil through its system and mechanical behavior was observed.
RESULTS

The final rendition of this filter cart ended up satisfying all the constraints specified by the sponsor. The overall height of the cart is 4’ 6”; it is 3’ wide and 4’ long. The reservoir is 28-gallons and is removable from the cart without disturbing any of the filtering components. Maximum working oil pressure observed was 20 psi with 80 psi of air pressure. The flow indicator on the four-filter manifold was a solid green, and best of all there were no leaks!

Unfortunately, the machine on which this project was tested became incapable of having its hydraulic system dynamically filtered. An oil sample was pulled from the machine before the testing started and another was pulled after an hour of the cart cycling. The oil samples were sent to a Caterpillar laboratory in Fresno, CA for analysis and returned with results that weren’t as hoped, but good none-the-less. Appendix C gives results of the oil sample taken before testing began. The description indicates that the particle count is “high.” The oil sample taken after the one hour trial resulted similar results except the adjective used this time is “elevated.” Jared Jewett of Quinn Rentals in Santa Maria expressed in an interview that “elevated” means the particles are lower in count than if they are “high” (Jewett, 2012).

During the demonstration of the filter cart on the job site off of Highway 46 in Paso Robles, CA, the objective was to gain familiarity with its function. Since the hoses were pumping and returning the oil to a bin that was open to atmosphere, there was not much resistance the oil encountered. The average working pressure of the filter system was about 8 psi with 20 psi of air pressure from the service truck. This demonstration proved beneficial to the mechanics as they were able to physically see the amount of oil that is moved with each cycle of the pump.

Figure 49. Filter cart fit in the service truck.
DISCUSSION

Fabrication

**Difficulties.** A major difficulty encountered early on in the project was with the fabrication of the frame. To construct the frame, three rectangles had to be made from square tube with mitered ends. It was tedious to keep the four pieces of the rectangle in plane as well as square. Making a cube with two levels, from three rectangles and some vertical pieces, was the most difficult. Lots of time was taken to check and double-check that the main frame was still square while slowly spot welding as progress continued.

**Design Changes.** During the design of the reservoir, a mistake was made when the dimensions were being determined. The dimensions of the reservoir were determined by virtue of the space provided under the pump mount and between the two reservoir brackets. The width had to have enough room to weld the drilled and tapped slugs on the sides of the reservoir and still fit between the brackets. The width of the reservoir turned out well, however the length was calculated without any buffer factored in and was a ¼” too long to fit between the ends of the cart. This issue was caught and corrected before the reservoir was fully welded. One inch was cut from the end opposite of the access hole and later welded back together.

Cost Analysis

**Materials.** Cost of materials for this project came to a total of $3,084.56. Materials were mostly sourced from local vendors including Contractor’s Maintenance Supply, JB Dewar, Miner’s Ace Hardware, B & B Steel Supply, and Quinn-Cat Rentals.

**Estimated Labor.** This project was worked on twice a week for five hours on average and began January 3rd. The project was complete for initial testing by March 28th making the total build time about twelve weeks. Total hours for this project are estimated at around 120. If an average welding shop in San Luis Obispo, CA was to build this cart, labor would cost $10,200 at a rate of $85/hr.

**Total Estimated Cost vs. Competition.** With the materials cost and labor cost estimation, the total estimated cost for an average welding/fabrication shop to recreate this project is estimated at $13,284.56. Compare this cost to that of the filter cart from Quinn-Cat which was price quoted to the project sponsor for $10,000. The Quinn-Cat filter cart does not come “turn-key;” it comes on a crate and must be assembled by the buyer. This project was a risk Papich Construction was willing to accept and it saved them about $10,000. They receive a ready-to-use machine at less than market price and it is custom built for their application.
RECOMMENDATIONS

Having had reference to the Quinn-Cat filter cart allowed for a strong start in the right direction as to the expectation of the sponsor. This cart has a four-filter manifold and a single filter head in series; having the project oriented in series was instantly subconsciously part of the design. Little consideration was given to the possibility of running the system with a different pump in parallel fashion. The pump would be suited to this application if it had two outlets and sent them each through three filters. This design would allow for more uniformity between the filters. The oil would combine into a larger orifice to be pumped back into the hydraulic system.

A parallel system could have worked with the pump chosen for this project as well by sending the oil through a wye with two ¼” plumbing lines, through the filters and combining them back into one 1½” line. The parallel design is theoretically more beneficial to use since the dirtiest oil is spread across twice the area as the single filter with the series design. As the filters accumulate debris, the force required for moving the oil through the filter’s element increases which affects the flow rate; the pump speed would have to be increased to compensate. With a parallel system, the flow rate would decline slower than the series system making it beneficial for long periods of self-sustained use.

The frame of this project was dimensioned based on the plumbing components, intent for a toolbox to be mounted later on, and several scaled drawings. Now that the lead on the paper has become reality the frame seems unnecessarily bulky. Six inches could easily be spared from the length and width. The height of the frame itself without the casters is just right. However, a smaller wheel size would be an improvement; the caster’s can be two inches smaller in diameter and still meet constraints. This would allow the cart to be shorter and easier to maneuver.

It is highly recommended that the filter cart be used for more than one hour on a hydraulic system. This cart should be placed on a system for at least four hours to get accurate data regarding performance. A longer operating time would give the cart a chance to move the entire volume of hydraulic oil through the filters several times. The hydraulic system of one of Papich’s scrapers is approximately 60 gallons. Each cycle of the pump on the filter cart moves a half-gallon of oil. During the demonstration, with the given input pressure and system oil pressure the pump was producing one cycle a second; that’s 30 gpm for the scenario. If the cart can maintain this flow rate when hooked up to a scraper’s hydraulic system, the whole system would be pushed through filters every two minutes. There is a risk of filters plugging up with contaminants, yet the parallel design of the four-filter manifold, and the internal by-pass ports within the filter heads will help protect the system and with the pressure gauges the system can be closely monitored.
REFERENCES


APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR
HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

ASM Project Requirements
The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving. This project addresses these issues as follows.

Application of Agricultural Technology. The project involves the application of mechanical systems, power transmission, and fabrication technologies.

Application of Business and/or Management Skills. The project involves business/management skills in the areas of machinery management, cost and productivity analyses, and labor considerations.

Quantitative, Analytical Problem Solving. Quantitative problem solving techniques include the cost analysis, design drafting, and the shear stress calculations of mounted reservoir.

Capstone Project Experience
The ASM senior project must incorporate knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 152 SolidWorks
- BRAE 142 Machinery Management
- BRAE 301 Hydraulic/Mechanical Power Systems
- BRAE 342/343 Mechanical & Fabrication Systems
- BRAE 418/419 Ag. Systems Management
- ENGL 145 Expository Writing

ASM Approach
Agricultural Systems Management involves the development of solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving. This project addresses these issues as follows.

Systems Approach. The project involves the investigation of oil cleanliness mandates within public and private sectors. It involves the integration of machine/operator management systems to provide an improved fluid management solution for companies with assets that depend on hydraulic oil as their lifeblood.
**Interdisciplinary Features.** The project includes aspects of mechanical systems and fluid mechanics while reducing waste oil.

**Specialized Agricultural Knowledge.** The project applies specialized knowledge in the areas of mechanical and fabrication systems as well as agricultural safety.
APPENDIX B

QUINN FILTER CART LITERATURE
Figure 50. Cost of Quinn filter cart (Jewett).
Figure 51. Quinn filter cart (Jewett).

Figure 52. Quinn filter cart data list (Jewett).
APPENDIX C

OIL SAMPLE RESULTS
Figure 54. Oil sample after.
Figure 55. Example of brand new oil and contaminated oil.
APPENDIX D

PARTS LIST/COST SHEET
### Parts List Final

#### Hydraulic Oil Filtration Cart

<table>
<thead>
<tr>
<th>Frame</th>
<th>Quantity</th>
<th>Description</th>
<th>Unit Price</th>
<th>Total</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Tubing</td>
<td>2</td>
<td>21’ Stick 1 1/2” x 1 1/2” x .1875”</td>
<td>$52.95</td>
<td>$105.90</td>
<td>B&amp;B Steel</td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>1</td>
<td>4’ x 8’ Sheet 10 GA</td>
<td>$131.20</td>
<td>$131.20</td>
<td>B&amp;B Steel</td>
</tr>
<tr>
<td>Caster Wheels</td>
<td>2</td>
<td>8” swivel w/ brake, no-flat pneumatic tire</td>
<td>$36.96</td>
<td>$73.92</td>
<td>Access</td>
</tr>
<tr>
<td>Caster Wheels</td>
<td>2</td>
<td>8” fixed w/o brake, no-flat pneumatic tire</td>
<td>$32.69</td>
<td>$65.38</td>
<td>Access</td>
</tr>
</tbody>
</table>

#### Hardware

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Quantity</th>
<th>Description</th>
<th>Unit Price</th>
<th>Total</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump Mount Bolts</td>
<td>4</td>
<td>7/16” x 3”</td>
<td>$0.82</td>
<td>$3.28</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Caster Bolts</td>
<td>8</td>
<td>3/8” x 1”</td>
<td>$0.22</td>
<td>$1.76</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Filter Bracket</td>
<td>6</td>
<td>7/16” x 1 3/4”</td>
<td>$0.25</td>
<td>$1.50</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Tank Hatch Bolts</td>
<td>14</td>
<td>3/8” x 3/4”</td>
<td>$0.35</td>
<td>$4.90</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Pump Bolts</td>
<td>4</td>
<td>5/16” x 1”</td>
<td>$0.24</td>
<td>$0.96</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Tank Mount Bolts</td>
<td>8</td>
<td>1/2” x 1”</td>
<td>$0.27</td>
<td>$2.16</td>
<td>Miner’s</td>
</tr>
</tbody>
</table>

#### Fluid Transfer

<table>
<thead>
<tr>
<th>Fluid Transfer</th>
<th>Quantity</th>
<th>Description</th>
<th>Unit Price</th>
<th>Total</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump</td>
<td>1</td>
<td>Graco Husky Model: 1590 dual-diaphragm pneumatic oil pump (DB3525)</td>
<td>$966.00</td>
<td>$966.00</td>
<td>JB Dewar</td>
</tr>
<tr>
<td>Pipe</td>
<td>1</td>
<td>4’ Length 1 1/2” Black Pipe</td>
<td>$26.65</td>
<td>$26.65</td>
<td>Miner’s</td>
</tr>
<tr>
<td>2” Nipple</td>
<td>2</td>
<td>1/ 1/2” NPT Black Pipe</td>
<td>$2.84</td>
<td>$5.68</td>
<td>Miner’s</td>
</tr>
<tr>
<td>4” Nipple</td>
<td>5</td>
<td>1/ 1/2” NPT Black Pipe</td>
<td>$3.48</td>
<td>$17.40</td>
<td>Miner’s</td>
</tr>
<tr>
<td>8” Nipple</td>
<td>1</td>
<td>1/ 1/2” NPT Black Pipe</td>
<td>$10.38</td>
<td>$10.38</td>
<td>Miner’s</td>
</tr>
<tr>
<td>Weld Bung</td>
<td>1</td>
<td>1/ 1/2” NPT</td>
<td>$3.38</td>
<td>$3.38</td>
<td>Boyd</td>
</tr>
<tr>
<td>Weld Bung</td>
<td>1</td>
<td>2” NPT</td>
<td>$3.88</td>
<td>$3.88</td>
<td>Boyd</td>
</tr>
<tr>
<td>Bushing</td>
<td>1</td>
<td>2” Male NPT to 1 1/2” Female NPT</td>
<td>$8.25</td>
<td>$8.25</td>
<td>CMS</td>
</tr>
<tr>
<td>90° Elbow</td>
<td>5</td>
<td>1/ 1/2” NPT Black Pipe</td>
<td>$8.11</td>
<td>$40.55</td>
<td>CMS</td>
</tr>
<tr>
<td>Union</td>
<td>3</td>
<td>1/ 1/2” NPT</td>
<td>$9.19</td>
<td>$27.57</td>
<td>CMS</td>
</tr>
<tr>
<td>Hose</td>
<td>16 ft</td>
<td>1 1/2” 150 PSI (PN: CAT 844-24)</td>
<td>$21.96/ft</td>
<td>$351.36</td>
<td>Quinn</td>
</tr>
<tr>
<td>3-Way Diverting Valve</td>
<td>2</td>
<td>1 1/2” NPT Brass Apollo Ball Valve</td>
<td>$130.00</td>
<td>$260.00</td>
<td>CMS</td>
</tr>
<tr>
<td>Hose Ends</td>
<td>2</td>
<td>1 1/2” NPT</td>
<td>$35.86</td>
<td>$71.72</td>
<td>Quinn</td>
</tr>
</tbody>
</table>

#### Fluid Filtration

<table>
<thead>
<tr>
<th>Fluid Filtration</th>
<th>Quantity</th>
<th>Description</th>
<th>Unit Price</th>
<th>Total</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filters</td>
<td>6</td>
<td>10 Micron, spin-on (PN: CAT 9U-5870)</td>
<td>$67.41</td>
<td>$404.46</td>
<td>Quinn</td>
</tr>
<tr>
<td>Filter Head</td>
<td>1</td>
<td>1 1/2” NPT 4 filter filter manifold (PN: CAT 229-7261)</td>
<td>$252.91</td>
<td>$252.91</td>
<td>Quinn</td>
</tr>
<tr>
<td>Filter Head</td>
<td>2</td>
<td>1 1/2” NPT single filter head (PN: CAT 229-7259)</td>
<td>$55.21</td>
<td>$110.42</td>
<td>Quinn</td>
</tr>
</tbody>
</table>

#### Instruments & Control

<table>
<thead>
<tr>
<th>Instruments &amp; Control</th>
<th>Quantity</th>
<th>Description</th>
<th>Unit Price</th>
<th>Total</th>
<th>Source*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Regulator</td>
<td>1</td>
<td>1/2” NPT 100 PSI max</td>
<td>$88.00</td>
<td>$88.00</td>
<td>CMS</td>
</tr>
<tr>
<td>Air Pressure Guage</td>
<td>1</td>
<td>0-100 PSI 1/8” NPT</td>
<td>$6.39</td>
<td>$6.39</td>
<td>CMS</td>
</tr>
<tr>
<td>Oil Pressure Guage</td>
<td>2</td>
<td>200 PSI Wet</td>
<td>$18.23</td>
<td>$36.46</td>
<td>CMS</td>
</tr>
</tbody>
</table>

**Total** = **$3,084.56**

---

*Source Directory:

- B&B Steel Supply: (805) 349-9999
- Access Casters Inc.: (877) 881-6814
- JB Dewar: (805) 543-0180
- Miner’s-Ace Hardware: (805) 543-2191
- Quinn-Cat: (805) 925-8611
- Contractor’s Maint. Supply: (805) 543-4558
- Boyd Welding: Boydwelding.com

1233 Furukawa Wy. Santa Maria, CA 93458
10241 S. Western Ave. Chicago, IL 60643
75 Prado Rd. San Luis Obispo, CA 93401
2034 Santa Barbara Ave. San Luis Obispo, CA 93401
1655 Carlotti Dr. Santa Maria, CA 93454
3440 #B Sacramento Dr. San Luis Obispo, CA 93401

Figure 56. Parts list with cost.
APPENDIX E

DESIGN CALCULATIONS
Design Calculations

Reservoir Dimensions.

1. Cart length – tubing
   a. 48” – (1.5” x 2) = 45” – 1” Buffer = 44” Long
2. Cart width – tubing – brackets
   a. 36” – (1.5” x 2)-(5” x 2) = 23” – 2” Buffer = 21” Wide
3. Depth= 7”
4. Reservoir Capacity= 44” x 21” x 7”= 6,468 in³ ÷ 231 in³/gallon= 28 Gallons

Tear-Out Calculations.

1. Reservoir mounting bolts
   a. 1½ x Hole Diameter
      i. 1½ x ½” = ¾” from edge

Dirt holding capacity with 10 micron filters:

1. 64g x 6 filters=384g x 0.035274 oz/g=13.5 oz x 0.0625 lb/oz= 0.85 lb

Table 3. Compatible filter elements with chosen filter heads.

<table>
<thead>
<tr>
<th>Nominal Micron Rating</th>
<th>Media Material</th>
<th>Dirt Holding Capacity</th>
<th>Height</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Synthetic</td>
<td>—</td>
<td>289.3 mm (11.39 in)</td>
<td>158-3188</td>
</tr>
<tr>
<td>5</td>
<td>Synthetic</td>
<td>64 g (2.26 oz)</td>
<td>289.3 mm (11.39 in)</td>
<td>9U-6983</td>
</tr>
<tr>
<td>10</td>
<td>Synthetic</td>
<td>64 g (2.26 oz)</td>
<td>270.8 mm (10.66 in)</td>
<td>9U-5870</td>
</tr>
<tr>
<td>18</td>
<td>Synthetic</td>
<td>90 g (3.17 oz)</td>
<td>270.8 mm (10.66 in)</td>
<td>9U-6984</td>
</tr>
<tr>
<td>15</td>
<td>Synthetic / Cellulose</td>
<td>Water-0.57 g (20 oz)</td>
<td>270.8 mm (10.66 in)</td>
<td>168-7027</td>
</tr>
<tr>
<td>149</td>
<td>Cellulose / Wiro Mash</td>
<td>—</td>
<td>289.3 mm (11.39 in)</td>
<td>9U-6985</td>
</tr>
</tbody>
</table>