An Affordable Modular Rotary Evaporator

By: Smaerd

Introduction:

Many amateur chemists and under-funded institutions need affordable equipment. Rotary evaporators brand new can cost up to $4,000 *[US dollars]*. Many replacement parts are in the $20[1]-$350[2] range. Buying a used quality rotary evaporator motor assembly costs around $100 usually in broken condition, more likely towards $500 in working good condition. When a rotary evaporator breaks it costs an experimenter or institution a large amount of money. Many models of used rotary evaporators are also discontinued so replacement pieces are not always available. Thus, there is a desire to find ways to improvise such an apparatus effectively.

The main goals for such an apparatus should focus on modular design, affordable parts, ease of construction and be effective. A modular design is important because it allows for a failure in the device to be isolated and replaced. A design by R.V. Hoffman[3] uses a machined Teflon rotor. This rotor consists of a ST 24/40 end for a flask or bump-trap, and a ball-joint on the other end. Set screws were used to mount this rotor to a pillow block-bearing as well as a pulley, which is belt-driven by a D.C. motor. This design is claimed to be functional and there is no reason to suspect it is not. However, if there is a failure in the rotor the main component must be machined again.

The design implemented here-in features modular components. Such that, if the Teflon attachments are succumbed to degradation by torsional creep, mechanical or thermal means, they can be easily replaced. Another distinct advantage to building a rotary evaporator is that buying the pieces to make one will likely involve getting spare parts through package purchases and excess of simple materials. The modular rotary evaporator featured in this article costs about as much or significantly less then many replacement pieces of commercial rotary evaporators.

Materials:

Mechanical:

Material	Cost
-1” O.D. Teflon rod 12” in length	$15.00
-1” I.D. Axle Shaft Collar	$1.99
-12” 6061 Aluminum Tube 1” O.D. 3/4” I.D.	$2.41
-1” I.D. Pillow Block Bearing	$8.50
-1" Single groove v-belt sheave 3.05" O.D. 1" bore	$13.95
-4mm I.D. Shaft collar	$1.50
-2.5” O.D. Plastic Rope Pulley	$4.00
-3/4” O.D. X 9/16” I.D. X 3/32 O-Ring	$2.00
-19”Nominal length V-Belt	$4.00
-#6-32 Set-screw	$2.00
-Series of bolts and washers	~$8.00
-Plank of 1” by 6” by 36” wood	~5.00
-PTFE Plumbers Tape	$0.50

Note: costs are as of 1/23/2013 in USD, some are approximated. Shipping not included.

Electrical:

Item	Cost
-100RPM(or higher) high torque gearbox motor. Shaft 4mm	$10
-SPST switch	$1.99
-Potentiometer	$2.30
-12V 1A cell-phone charger	$4.00
-Aluminum or Plastic electronic project box	$5.00
- Wire and solder	$5.00

Note: costs are as of 1/23/2013 in USD, some are approximated. Shipping not included.

Approximate total cost:

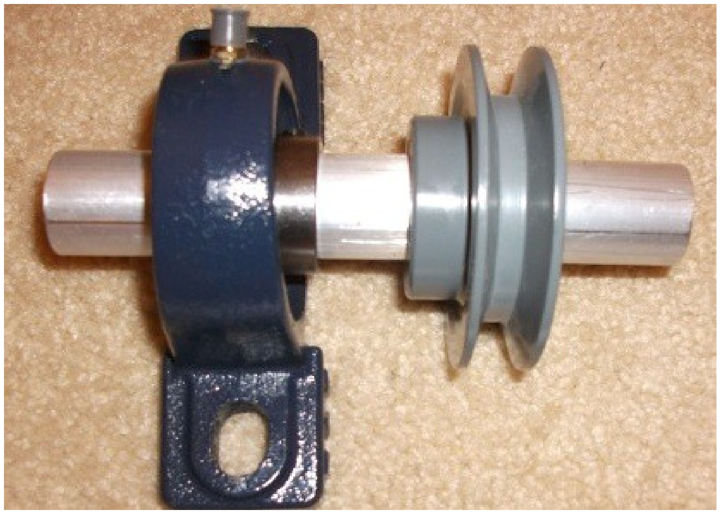
Materials:	$95.15
Labor:	$20.00
Total:	$115.15

Note: costs are as of 1/23/2013 in USD, some are approximated. Shipping not included.

Tools:

- Drill-press[assortment of drill-bits]
- Sanding attachment to drill-press [optional but may be necessary]
- Soldering iron[shrink-tube as well as electrical tape]
- Lathe[needed for the ball-joint] or access to a lathe or machinist
- Saw/jig-saw/hack-saw
- File
- #6-32 tap and appropriate drill bit
- Permanent marker
- Tin snips

Construction:



A piece of paper is wrapped around the aluminum tube at 6” of length and taped such that the paper makes a nice line to cut along. A hack-saw is used to cut through the tubing to about half its depth along the paper line, the tube is then twisted, and cut again all the way through. A file is used to smooth the cut as well as smooth the inside and out-side of the bore.

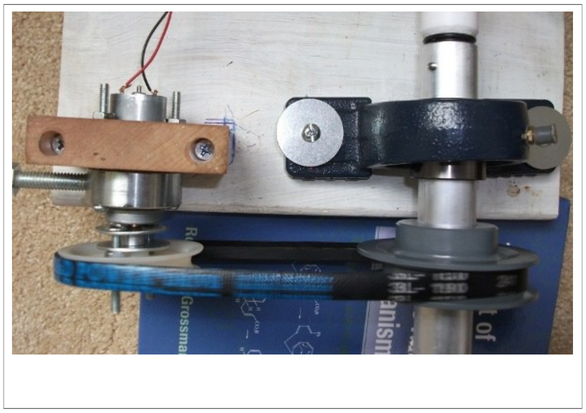
¼” on the tube a mark is made with the marker on both ends. A drill is used with the appropriate drill bit for the tap to put holes where these marks are. The holes are then hand tapped with a vice-grip using oil and a slow motion. Backing out occasionally to remove aluminum shavings and ensuring a good tap.

The metal pulley and the bearing are seated where they are desired on the aluminum tube. Marks are made through the set-screw holes to show where to file down the aluminum tube. A file is used to make indentations for the set-screws. A drill could be used instead. The pulley and bearing are now seated with the set-screws.

A Teflon ball-joint is machined using a lathe preferably to fit a ST 18/9 ball and socket joint convention. The attachment is made to be 2.5 inches long, and it's other end is machined to fit loosely into the aluminum tubing. A hole is drilled through this exactly in the center. A Teflon ST 24/40 attachment is made in a similar fashion. The ST 24/40 attachment can be made using only a drill-press and a sanding attachment. This provides a nice rough finish to better grip the flask. Although, it is time-consuming and easy to screw up. *Note: a friendly machinist or a local “hack-space” may make these for a small fee.*

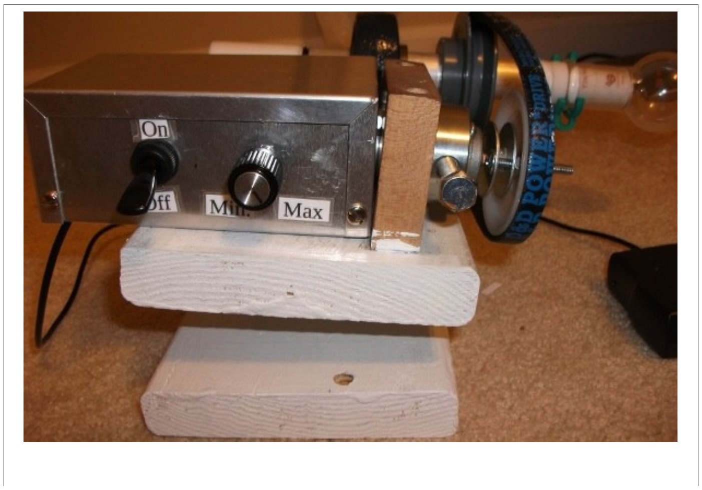
The attachments are placed into the aluminum tubing and a permanent marker marks points on the Teflon for which to drill slight indentations into the material. This is for the set-screws. An o-ring is placed on the Teflon attachment and fed snugly into the aluminum tubing. This may be difficult but a flat-head screw-driver can be used to coerce the o-ring into the tubing. The set-screws are then wrapped in Teflon tape then gently screwed into the aluminum tubing and screwed further into the indentations on the attachments. The junction where the Teflon meets the aluminum an extra o-ring is sat, and is wrapped with Teflon plumbers tape to further ensure an air-tight seal.

Two ~1.25” diameter washers are drilled at the same points equal distances apart from their centers. The rope pulley is removed from its casing which took effort. The plastic pulley is then drilled the same way the washers are. The 4mm shaft collar is sandwiched between the washers and is screwed onto the D.C. motor shaft. Two bolts go through the washer holes and are clamped tight each with a nut. The pulley is then placed onto these bolts and is tightened down with nuts. Alternatively the appropriate sized pulley may be bought or machined. It would likely be a rare find to buy, and machining one may cost a lot of money.

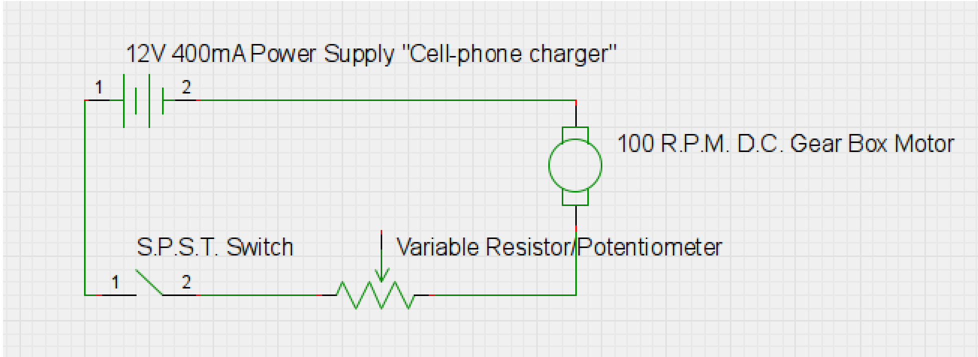


A small block of wood(4”x3”x1”) is drilled to have a bore the same size as the diameter of the D.C. motor. The 1” shaft collar has two holes drilled through it slowly using oil and a diameter of a drill bit to fit a bolt as well as to not break while drilling. The shaft collar is mounted onto the block of wood and two whole are punched through the holes of the shaft-collar and through the wood. The shaft-collar was then fit onto the wood with the motor inside using two bolts and tightened with nuts. The motor then is filed down slightly so that the set-screw of the shaft collar can keep the motor stationary while it spins.

This small block of wood is fixed to another larger plank of wood(6”x12”x1”) using nuts, washers and bolts. The pillow block bearing is fixed in such a way that it pulls the V-Belt taught when strung on the D.C. motor pulley and the V-Belt pulley on the rotor shaft. The pillow block bearing is also fit onto this larger plank of wood using bolts nuts, and washers.



An aluminum project box is cut with tin-snips so that the back end of the motor and bolts holding the axle collar can fit inside the box. Two holes are punched into the side of the project box to fit the switch and the potentiometer. The switch and potentiometer are then screwed into place using the parts that come with them. Another small hole is punched into the project box to allow the wire from the phone charger to come out of. A hole is punched through the bottom of the project box so that it can be mounted to the wooden board.



Circuit diagram created with easyspice.[4]

The electric circuit is incredibly simple. The 12V 1A phone charger charging attachment is cut off.*[Note: the charger actually puts out ~400mA, tested by multimeter]*. The positive lead of the charger is soldered to the SPST switch terminal which is wired to the potentiometer and then to the motor terminal. The negative lead goes straight to the motor terminal. A small non-polarized capacitor can be soldered between both pins of the electric motor to smooth out the electrical noise from back E.M.F. Once this is done the project box is screwed into place and closed.

Four holes are punched through the large wooden board(one in each corner). Another board the same dimensions also gets these four holes punched into them. Four large bolts using several washers and nuts are fed through these holes. The top board is not fastened down with nuts and rather has the nuts beneath the board to suspend the upper board holding the circuit and rotor assembly. These nuts are used to adjust the pitch of the rotary evaporator so that an attached flask can be angled down into a warm water bath. Or a bowl of water heated by a hot-plate. The build is now completed.

Experimental:

First Test: Basic functionality

The Teflon ball joint and ST 24/40 attachment were greased lightly with silicone faucet grease. 10mL of a mixture of ethanol/methanol was added to a 50mL flask and was loosely Keck clipped onto the rotary evaporator. A vacuum was applied via a glass ST 18/9 socket joint to the Teflon ball-joint from a water aspirator. Without rotation or external heating the solvent boiled gently in the flask. This ensured that a vacuum is being maintained. The flask was gently heated by a warm water bath and rotation was begun by turning the flipping the SPST switch. The solvent was ripped quickly and successfully.

Second Test: Timed trials for rotary vacuum evaporation of acetone

The flasks used for all trials were the same. Meaning that the 50mL and 100mL flask in Trial #1 is the same as the 50mL and 100mL flask in Trial #2 and Trial #3. The rest of the details are implicit.

Trial #1: Warm water bath trial without vacuum or rotary evaporation:

Acetone	Flask Size	Time(sec)	mL/min
10.0mL	50mL	422 S	1.42mL/min
20.0mL	100mL*	677 S	1.77mL/min
30.0mL	100mL*	937 S	1.92mL/min
Calculated Average Rate(mL/min):			1.71mL/min

Note: Without boiling stones. Flask was mostly submerged in the water. Water was hot enough to distill acetone before flask was submerged. Time was started as soon as reflux began and ended as soon as there was no visible liquid in the flask. The glass-ware set-up was that of a simple distillation.

Trial #2: Vacuum assisted trial without rotary motion:

Acetone	Flask Size	Time(sec)	mL/min
10.0mL	50mL	102 S	5.88mL/min
20.0mL	100mL*	158 S	7.59mL/min
30.0mL	100mL*	225 S	8.00mL/min
Calculated Average Rate(mL/min):			7.16mL/min

Note: Flask was half-way submerged in the water. Water was warm before flask was submerged. Time was started after the flask was placed into a warm water bath and as soon as the vacuum was applied. Stirrer was set on it's highest setting. The glass-ware set-up was that of a simple vacuum distillation.

Trial #3: Vacuum assisted trial with rotary motion:

Acetone	Flask Size	Time(sec)	mL/min
10.0mL	50mL	93	6.45mL/min
20.0mL	100mL*	113	10.62mL/min
30.0mL	100mL*	212	8.49mL/min
Calculated Average Rate(mL/min):			8.52mL/min

Note: Water was warm before flask was placed in bath. Time was started as soon as vacuum started and ended as soon as there was no visible liquid in the flask. The rotary evaporator featured in this article was the device used.

Results and Discussion:

On it's highest speed setting, with an empty 50mL flask as a load, the motor speed was about 80 R.P.M. When the motor needs to be replaced it will be replaced with a much faster high-torque motor. Probably around 150 R.P.M. Most commercial rotary evaporators can spin faster then 80 RPM though the work of this article still demonstrates the basic usefulness of the device.

The main problem with this design is a possibility for air-leaks from broken o-rings. The o-rings are not anticipated to wear because of the way they were to put into place and the flow of solvent should be concentrated through the Teflon attachments rather then around them. It will be interesting to see what breaks and what holds up over time with this design. This article will be updated to include such information as time progresses.

The comparison of the rate of evaporation using the three different methods is drastic in some respects. Removal of solvent at atmospheric pressure(Trial #1) is considerably slow. If 200mL of solvent needed to be removed, using the average calculated rates of evaporation the difference in time for the given operation becomes more meaningful. For example; Trial #1's method: 116 min, Trial#2's method: 27.9 min, and Trial #3's method: 23.5min. It is quiet clear that saving 80 minutes of time is important for productivity as well as a more fluid work-pace. Especially considering removing solvent isn't an enjoyable process during experimentation.

Although vacuum distillation rivals the rotary evaporator in rate of evaporation under conditions where there is a large amount of solvent verses flask surface area, it has other distinct disadvantages for solvent removal. Vacuum distillation requires either a stir-bar to be spinning constantly or an air inlet. The stir bar is a messy and inefficient verses simply spinning a flask. The air-inlet method also pushes air directly onto the sample being evaporated, which is not ideal for air sensitive compounds, though an inert gas stream can be used in either case. Vacuum distillation in this example also bumped vigorously where-as the solvent removed by rotary evaporation was done significantly more smoothly. Ultimately, putting a flask on a rotary evaporator is an easier process then setting up a vacuum distillation to remove a solvent under mild thermal conditions. It is also better suited for large scale solvent removal. These are some of the reasons why rotary evaporators are used in academia, as well as with-in industry.

Conclusion:

The modular rotary evaporator design works effectively, is affordable, and is reliable. The construction is sensible and offers most of the advantages of a commercial rotary evaporator at a fraction of the cost. The construction is such that the components susceptible to wear can be replaced with ease and at a significantly lower cost then commercial designs. This design is simplistic so when trouble-shooting any malfunction the solution should be intuitive and not require consultation or a technician.

References:

1)http://www.neobits.com/chemglass_cg_146_01_flange_buchi_50mm_flange_buchi_p3445785.html

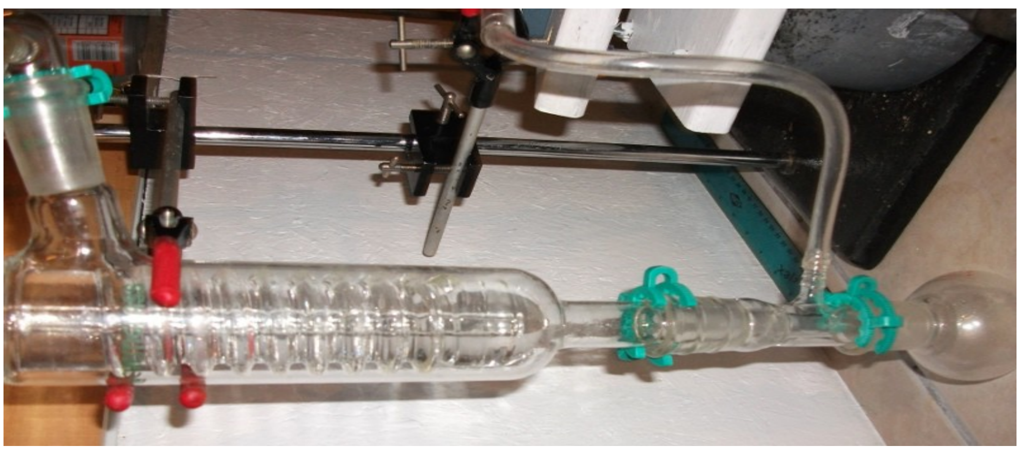
2)http://www.neobits.com/buchi_015502631_replacement_insert_glassware_each_p3378521.html

3)The construction of an inexpensive rotary evaporator, R. V. Hoffman, Journal of Chemical Education 1976 53 (7), 459.

4)http://easy-spice.sourceforge.net/

Photographs of device described:

Device running



Friedrich condenser condensing ethanol

An image of the vacuum connection. Note the special use of duct-tape. This area could be improved on.

Water bath at 40*C, flask rotating.

End result of the spun down sample, and collected ethanol.