PVC Experiments -First Rate Lab Apparatus from Plastic Plumbing, Adhesive, and Imagination.

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Abstract - *The present paper is intended to assist faculty who wish to develop undergraduate instructional laboratory apparatus, but who have only limited financial resources available. The paper attempts to make interested faculty aware of how simple, low cost, readily available PVC materials and products can be utilized to create first rate laboratory experiments. Although much of the information provided might be familiar to some home owners who undertake their own renovations and repairs, it is felt that the ideas expressed here may prove to be a revelation to many faculty who had previously considered the purchase of packaged experiments as their only option. Tips are given on types and sources of PVC, fabrication techniques, and some example experiments are discussed.*

Introduction

Money for buying undergraduate laboratory apparatus has never been plentiful, but the sky-rocketing price of packaged experiments has now made their purchase impossible for many schools. The only alternative to buying experiments is of course to build your own, but this can involve a large commitment of time in the design, ordering of components, and physical construction. Unfortunately, as any university professor will recognize, this time investment is often overlooked in the tenure and promotion process.

Over the last 10 years at USF a number of excellent experimental demonstration apparatus have been developed using mostly standard PVC materials. This approach is fast and cheap, since the components are available from common hardware stores, and PVC is simple to cut and solvent welds together readily.

This paper describes the advantages of PVC as a construction material, identifies the many different forms of PVC available [1], gives tips on fabrication techniques, and finally provides examples of experimental apparatus for use in mechanical, civil and chemical engineering curricula. Space constraints limit the inclusion of schematics, material suppliers, and detailed student laboratory instruction sheets, but these along with other example labs not mentioned here are available from the authors.

Advantages of PVC in Building Experiments

PVC shares advantages associated with many thermoplastics such as: corrosion resistance, resistance to chemicals, availability in different colors, noise damping and thermally insulating properties.

But in addition to the aforementioned properties PVC also has a number of unique desirable advantages, these are: PVC is .....

a) ... available as usefully shaped plumbing fittings (T's, elbows, flanges, reducers etc.).
b) ... available from common hardware stores.
c) ... available as fittings in many different sizes.
d) ... available in the form of screw unions, thus providing for moveable joints and disassembly.
e) ... available as check valves, ball valves, gate valves, foot valves and relief valves.
f) ... available as threaded fittings which allow connection to iron pipe, copper tube, and hoses.
g) ... available in clear, solid sheet, corrugated sheet, and expanded (foamed) sheet form from hobby shops and plastics suppliers.
h) ... inexpensive.
i) ... easily cut and bent.
j) ... quickly and easily solvent welded together to produce strong leak-proof joints.

There are however a few disadvantages to be considered also, these are: PVC .....

a) ... tends to become brittle with prolonged exposure to UV light (use indoors).
b) ... is not suitable as a "living hinge" since it will tend to fatigue.
c) ... does undergo large thermal expansion, making close tolerances difficult to maintain.
d) ... is an inferior dry bearing material as compared with Teflon and Delrin.
e) ... not suitable for high temperature applications, [2] (even hot water can increase creep especially under pressure)
f) ... is flammable and produces HCL when burned, [3].

Despite the few aforementioned shortcomings of PVC, its ready availability, abundance of standard forms and fittings, and ease of gluing, make it an invaluable material for quick, simple, low cost apparatus fabrication.

Available Forms of PVC Material

When one talks of PVC components, most people think of standard white pipe and plumbing fittings. Such material is the most readily available and the least expensive. Save for a thin-walled variant of pipe, the majority of white PVC plumbing is known as SCHEDULE 40 (SCHD 40), and is governed by many ASTM standards such as: D1785 & D2665 etc. SCHD 40 pipe is commonly available in nominal sizes 1/2", 3/4", 1", 1 1/4", 1 1/2", 2", 3" and 4", the former being for water supply while the latter is mainly for sanitary purposes such as sewers and drains. Larger diameters are available but only from industrial suppliers, where prices can be high, especially for short pipe lengths or small quantities of fittings. Nominal SCHD 40 PVC pipe size is loosely based on I.D. (bore). This is generally unimportant, but it should be noted that PVC pipe fittings are incompatible with most other plastic pipes (such as plexiglas) which are either measured by the outside diameter (O.D.), or have different wall thicknesses to PVC.

The nominal size confusion is further complicated by the availability of 1/2" and 3/4" CPVC, neither of which are anywhere close to the nominal size SCHD 40 equivalent. In fact, a substantial reducer is needed to connect a 1/2" PVC pipe to a 1/2" CPVC one. CPVC which is off-white in color is measured by the O.D. and has a substantially smaller wall thickness than SCHD 40, having been originally developed for compatibility with copper water pipe. CPVC is very useful for applications where small bore somewhat flexible pipe is needed, but it must be glued with special glue, although a general purpose adhesive is available for PVC-PVC, CPVC-CPVC and PVC-CPVC joins.

The white and off-white colors of PVC and CPVC make them susceptible to embrittlement from UV exposure, and also they tend to look ugly due to manufacturers markings, scuffing, dirt, grease and general wear and tear. SCHEDULE 80 (SCHD 80) is an alternative dark grey PVC which looks much more professional when used for exposed pipe experiments.The O.D. of SCHD 80 pipe is identical to SCHD 40 and so the pipe and fittings can be *mixed and matched.* However, for appearance it is best to use SCHD 80 throughout, even though the pipe and fittings may have to be purchased from industrial suppliers rather than hardware stores. SCHD 80 has a thicker wall (therefore smaller bore) than SCHD 40, which interestingly means that 1" SCHD 80 pipe has neither a 1" I.D. or O.D. The larger wall thickness none-the-less makes it physically stiffer and able to resist higher pressures.

The dark grey of SCHD 80 is not to be confused with the light grey of PVC electrical conduit which is also compatible with SCHD 40 fittings. The world of PVC electrical fittings offers an array of useful items such as square, round and rectangular boxes, large radius elbows, and pull-through elbows.

Another rich source of available plastic materials is for household trim such as gutters, fluted down pipes, soffit (solid and vented), J-channel, F-channel, siding, starter strips and facia. In the latter case, embossed versions are available with wood-grain surface finishes. This material is Vinyl rather than PVC, but can still be glued with PVC adhesives.

Finally, PVC is available in more exotic forms. EXCELON TUBE is a transparent form of SCHD 40 pipe, although it lacks the optical clarity of plexiglas (acrylic) it does fit standard fittings and can be solvent welded with regular PVC adhesives. Flexible and corrugated pipe is a further type that can be obtained. In addition to pipe and tube, PVC is also available in sheet stock. This includes grey sheet (plate) from 1/16" up to 1" thick, clear sheet, corrugated sheet, foamed sheet for lay-up work and a bright blue expanded sheet version. These sheets can be found in hobby/model stores or from industrial plastic suppliers.

PVC Fabrication Techniques

One of the great advantages of PVC is that it can be readily solvent welded. This process is accomplished in two stages: 1) cleaning/priming, 2) gluing. This procedure is most often performed when attaching plumbing fittings to pipe, but it is just as effective on sheet materials provided that joint tolerances are tight (minimal voids) and adequate pressure is applied. The priming and gluing materials are readily available from hardware stores, with special formulations provided for wet conditions (rain 'n shine), for showing where the glue has been applied (purple), for large fittings (slow set), for clean looking joins (clear), and for plastic combinations (general purpose PVC-CPVC-ABS). The solvent welding process is very quick and doesn't permit much repositioning after assembly. The process is also effectively irreversible, making joints virtually impossible to disassemble.

Bonding can also be achieved using epoxies, polystyrenes and cyanoacrylates (superglues), such joints are not as strong as solvent welding but can be disassembled using selective solvents that dissolve the bonding agent alone.

Sometimes it is not actually necessary to glue plumbing fittings together. "Dry" fitting can be most effective when minor leaks are acceptable (ie for submerged systems, or when using compressed air as the working fluid). Such an assembly method makes it possible to rearrange networks, swop out parts, and reuse fittings.

PVC can be machined easily, but care must be taken not to overheat the material as this causes the chips to soften or melt thereby clogging tools and ruining surface finish. It should also be noted that molded fittings rarely run true in a lathe, often demanding use of a 4-jaw independent chuck. PVC can be tapped, but fine or small diameter threads are better achieved using push-fitted metal inserts.

PVC pipe can be cut easily using scissor-type blade cutters, except for EXCELON transparent tube which tends to be fairly brittle and it better cut with a hack-saw. PVC may also be bent or curved using heating strips or hot air guns.

A valuable tip learnt over many years of building PVC pipe networks is to spend the little extra money and include plenty of unions (threaded collar type with integral o-ring). Such devices permit disassembly and are a must when a network includes threaded joints (into flow meters etc.), since leaking threaded joints (which should always be Teflon taped) cannot normally be tightened further once installed into a glued pipe network with elbows.

Example PVC Experiments

The authors of this paper represent three engineering departments: Mechanical, Civil and Chemical, and have been building experiments and demonstrations for use in the undergraduate laboratory for many years. Space constraints preclude detailed descriptions of every apparatus developed, but a few example cases will be provided to demonstrate the diversity of ideas and techniques. More details of the Mechanical Engineering department's experiments, and the course in which they are utilized, can be found in reference [4]

Mechanical Engineering

The department's undergraduate teaching lab currently contains four experiments which consist primarily of PVC.

The **Pump Experiment** contains nine water pumps of different design, networked into a SCHD 80 plumbing arrangement. This allows individual pumps to be selected to circulate water to and from a tank via a gate valve restriction. The network is all PVC and includes ball valves, check valves, a gate valve, a pressure relief valve, Excelon clear pipe sections, and unions for disassembly. Extensive use of PVC electrical fittings has been made to direct power to each selected pump motor. The apparatus includes an output pressure gage, a flow meter on the low pressure input side of the pumps, plus a voltmeter and ammeter for monitoring the electrical characteristics of each pump motor. These four basic instruments are used to determine all important pump parameters such as output pressure, discharge (volumetric flow rate), electrical input power, hydraulic output power, and efficiency.

The **Flow Meter Experiment** is again constructed from SCHD 80 PVC pipe and includes many home-built flow meters made from PVC flanges and fittings, such as an Orifice, Nozzle, Flow Tube, Pitot Tube and Elbow Meter. Additional purchased meters include all-plastic devices such as a Rotameter, Turbine, Paddle Wheel, By-Pass, Vortex and Nutating Disc. The output from the network discharges into a drain, but the flow can be accessed at this point and used to fill a weigh tank arrangement. This set up, together with the inclusion of a gate valve, provides a method of calibrating each flow meter in the network, and in so doing demonstrates any non-linearities and unique flow meter characteristics.

The **Free Jet Flow Experiment** is based on an idea by Brinkworth [5] and takes the form shown in Figure 1. The apparatus allows the relationship between head and flow rate to be studied for water discharge through orifices of various size and over weirs of different shape. The device is worthy of mention since the head tank is constructed from 12" diameter PVC pipe with a lower end cap, and the sliding head tube is accomplished using a PVC slip union. The orifice portion of the apparatus is useful in demonstrating some of the fluid principles involved in such engineering systems as fuel injectors, hoses and aerosol sprays. The weir provides the means of studying certain types of open channel flows.

The **Falling Sphere Viscometer** is an example of using Plexiglas (for optical clarity) in combination with PVC fittings and valves. To achieve this the fittings had to be bored out on a lathe to accept the plexiglas, and epoxy was used as the bonding agent between them. Ball valves were used to retrieve the fallen spheres, but to achieve this they had to be disassembled and modified by gluing discs into one end of the internal ball units. The valves thus act as small cups permitting sphere extraction without much mess or fluid loss. The apparatus uses plastic spheres of various size, and viscous liquids such as dish detergent, silicon and glycerin. The experiment does an excellent job of demonstrating Stokes' law and the measurement of viscosity, non-Newtonian fluid behavior, and the visualization of laminar wake flows.

Chemical Engineering

This department has a number of PVC based experiments, but often the high temperature nature of various reactions demands the more extensive use of glass. Two current PVC experiments are listed.

The **Losses Experiment** studies the effect of pipe diameter, pipe length, sudden expansions / contractions, elbows and valves on the head loss experienced by plumbing networks. This apparatus is unique in that compressed air is used and all components are "dry" fitted together. Each set up is thus created each time when needed, essentially from a *box of bits*. PVC, including excelon clear PVC, is also used to create water filled manometers as required for measuring the head losses.

The **Heat Exchanger** shows how PVC and Copper pipe can be married together to create an effective heat exchanger. Figure 2. shows the simple arrangement of fittings needed to achieve the exchange.

Civil Engineering

This department has been active in producing many unique PVC apparatus over the years, but a current emphasis has been placed on open channel flows. Recently a very elegant Flume has been created which is capable of many different functions. It is unique amongst the devices mentioned so far in that it incorporates PVC sheet stock.

The **Flume Experiment** is a portable, table top hydraulic flume externally constructed of plexiglas, but which includes several PVC models of control structures such as weirs, orifices and culverts. The flow rate can be controlled by locating one of these devices in the flow stream.

A simple example is discharge from a reservoir the magnitude of which is mostly determined by the shape and configuration of the aperture. Sharp edges tend to promote a free jet that contracts after springing free of the side of the aperture. While alternatively, extended sides along the flow path tend to attach the flow and increase discharge by maintaining a large flow area. PVC aperture models have been cut from grey sheet stock of various thicknesses, and with several edge geometries. Attachment and separation phenomena are clearly visible.

A more complex example of flow control occurs when culverts are inserted in an open channel flow. Several operational modes are possible, including weir and orifice flow at the inlet, or flows with the barrel completely full (outlet control). Models were fabricated from PVC sheet stock to form the end section and a clear Excelon tube was used for the barrel. The clear tube makes possible the observation of flow in the barrel, and in particular clearly shows the separation under inlet control. Unusual conditions such as air induction, vortex formation, barrel slugging and other interesting conditions can also be observed.

Other Possible Experiments

The experiments mentioned so have all involved fluids, either water, viscous liquids or air. However, the availability of plumbing fittings such as T's, elbows, 45 degree elbows, and flanges, opens up the possibility of building 3D structures. Such apparatus could provide experiments in the area of statics or dynamics. Examples of such experiments might include studies of portal frames, trusses or whirling of shafts.

Since PVC pipes comes in a variety of diameters they could be easily utilized in strength of materials studies, such as compressive specimens to demonstrate buckling, or specimens for use in impact testing.

Conclusion

PVC in its many forms has been proposed as a material eminently suited to the fabrication of laboratory apparatus. PVC is a good candidate for such a use since it is cheap, readily available from local hardware stores, solvent welds quickly and easily, and is offered in many shapes and sizes. Detailed information about the experiments covered, including schematics and student instruction sheets, are available from the authors.

References

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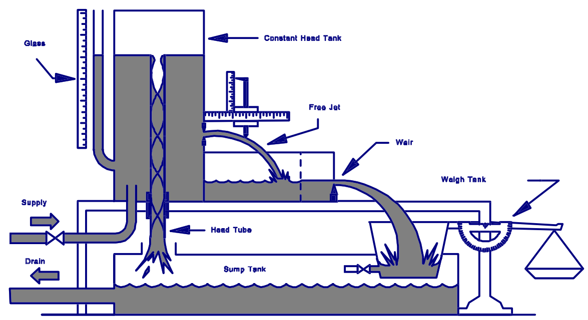

Figure 1. Free Jet Flow Experiment [1]

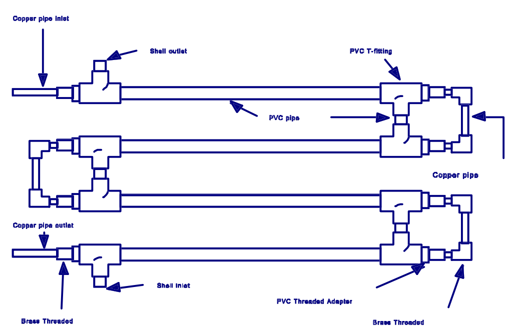

Figure 2. Heat Exchanger Configuration