Reprinted from *American Laboratory*, October, 1980

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Preparation of high-purity solvents

FOR YEARS users of analytical solvents have been confronted with the fact that absolutely pure liquids are difficult to obtain. In many cases they are not commercially available and must be prepared by means of tedious laboratory procedures. Some very pure liquids are so unstable that for storage they have to be recontaminated by the addition of a stabilizer, a step that requires them to be purified again shortly before each use. All of these factors contribute to the high price of pure solvents.

When considering the problem of solvents, the very first difficulty arises in defining the term "purity." Only in rare cases does purity mean that the solvent is solely composed of a single, well-defined compound. More often, this term is only specified for the purpose for which the liquid may be used rather than for clear identification of its chemical composition.

Not surprisingly, therefore, some of these liquids are specially prepared for use with specific, mostly spectroscopic techniques. As long as they satisfy the intended purpose there is no need to assay them for residues of the "purifying agents" such as sulfuric acid, mercury, NaOH, etc. However, since the early days of chromatography, it has been evident that even trace contaminants of the mobile phase interact with the stationary phases, as well as with the minute quantities of decontaminating reagent still present in the "purified" liquid phase. In liquid-solid and liquid-liquid chromatography, such undesirable constituents concentrate at the top of the column and reduce the capacity of the column relative to the sample. Also, they frequently disperse throughout the entire stationary phase, changing the separation environment unreproducibly and uncontrollably with sometimes detrimental results.

A study of actions and interactions of the solvent(s) with the stationary phase(s) suggested the appropriate procedure for the purification of the solvents in question. A chromatographic procedure appeared to be the best solution because the multiple-step, dynamic chromatographic process allowed the complete removal of contaminants to be accomplished more easily than a repeated step, static chemical and physical procedure did. In addition, chromatographers like the idea that the solvent(s) to be used already has a history of exposure to the stationary phase before entering the separation system as the mobile phase. The general applicability of such "chromatographically" pure solvents was realized as they came closer to the ideal purity of a single, defined compound. Also, in many cases improved stability was shown because the solvents were free of the trace contaminants that previously acted as catalysts for a formation of new bulk contamination.

For chromatographic purification of solvents, a

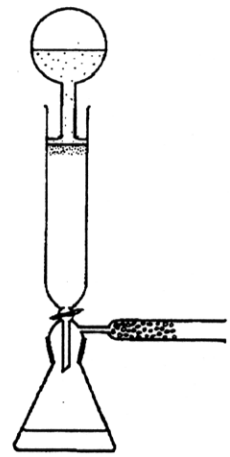

Figure 1 *Apparatus for the chromatographic purification of liquids.*

Mr. Moskovitz is President, Universal Scientific, Inc. *This paper was presented at the First Annual Chromatography Discussion Group Symposium, May 1979, Atlanta, Georgia. The author wishes to thank Dr. Bruno Engelbrecht of Woelm Pharma for his valuable assistance.*

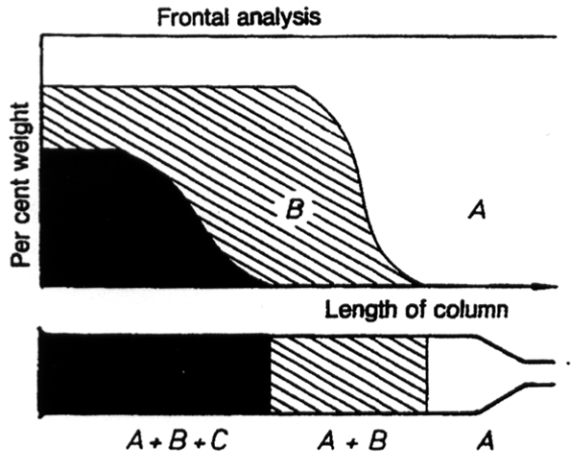

Figure 2 *Frontal analysis.*

very simple apparatus was used, consisting of the following components: reservoir, column, adsorbent, and receptacle. *Figure 1* provides a graphic representation of the apparatus for the chromatographic purification of liquids.

The receptacle was fitted with an outlet for several purposes: to maintain ambient pressure; to permit a purge with inert gas, or to attach a tube filled with desiccant. There are several advantages of this apparatus. The mechanical advantages include: the simple apparatus, the simple operation, and the high economy. The chemical advantages are: no contact is made with new potential contaminants; and the lowest possible residual contamination is offered, along with high stability, the wide range of types of solvents that can be purified, and the wide range of possible applications of purified solvents.

Essentially, the reaction that accomplishes the purification is simple. The mechanism may be defined as a frontal analysis type: one pure substance, A, runs in front and leaves the sorbent bed. After the capacity of the bed has been exhausted A will be followed by varying concentrations of B in A. After these mixtures other mixtures such as A+B+C, A+B+C+D, etc. will follow. The first fraction leaving the column A will constitute the pure solvent (see *Figure 2*).

This fact limits the practicability of the method. Only those compounds that have a lower polarity than their impurities can be purified by a given sorbent; that is, the impurities must have a stronger retention than the solvent, for example the removal of water (ε H_2O = 21) from hexane (ε_{Hex} = 0.01) by a bed of highly active alumina.

The method also applies to cases where the situation is less extreme. It will not succeed, however, if the polarity of the contaminant is close to that of the solvent.

Another example: The removal of water (ε H_2O = 21) from ethyl alcohol (ε_{EA} – 11.2) cannot be achieved economically even if alumina of the highest possible activity is used.

When a mixture of certain components cannot be separated by the sorbent on hand one should change to a sorbent of such type where the compounds alcohol and water exhibit widely different forces toward the surface of the solvent. For example, to dehydrate alcohol a bed of activated molecular sieves of the zeolithic type that have a different specifity toward water and ethanol molecules should be used.

Sometimes it appears advantageous to use columns filled with two different sorbents, such as one layer or bed of alumina on top of another layer of silica. A combined column of this type may well use the anion exchanging properties of an acid and active alumina plus the specific retention properties of a cation exchanging silica gel.

When assaying for the residual of the eluate of a column, two facts are evident:

1. The residual concentration of the contaminant(s) is a function of the specificity and of the activity of the sorbent used.
2. The breakthrough point for the contaminant on the column is a function of the capacity that the sorbent still exhibits after having contact with the solvent.

These phenomena can be demonstrated easily by a column made of the highest possible active alumina (Super 1) because it exhibits a capacity that is practically two times greater than a comparable Brockmann 1 alumina column. (See *Table 1.*)

As a rule, U-shaped curves will be received if the concentration of the impurity is plotted vs the elu-

Table 1

Dependence of column capacity upon sorbent activity*

	Alumina B Activity 1 mL	Alumina B Act. Super 1 mL
Diethyl ether, dry	250	500
Diethyl ether, H_2O-sat'd	200	450
Diisoprophyl ether, dry	350	500
Diisoprophyl ether, H_2O-sat'd	300	400
Dioxane, dry	200	400
Dioxane + 2% H_2O	50	100
Tetrahydrofuran, dry	115	250
Tetrahydrofuran + 1% H_2O	45	85

**Yield of peroxide-free solvents after percolation through 25 g Woelm aluminas.*

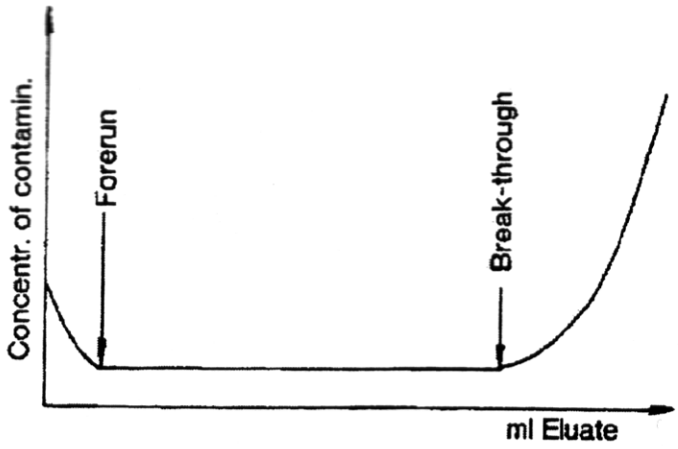

Figure 3 *Typical elution curve.*

ate volume. The intersection of the slope with the base line close to zero indicates the end of the forerun. Because the forerun is of lower quality it should be recycled. The fact that such a forerun exists (indicated by the slope) means that either the column has cleaned itself by the percolation of the liquid and/or it required some time to equilibrate the column in order to give optimum performance. A slope at higher volumes indicates the reappearance of the impurity. Here, the point of inflection, the intersection with the baseline, is equivalent to the exhaustion of the column. The plate between forerun and breakthrough point and the difference of the two columns (V breakthrough − V forerun = Cap) equals the capacity of the column. (A typical elution curve is shown in *Figure 3*.)

There are cases where a minimum concentration is not absolutely necessary. Here, the forerun should not be discarded. *Figure 4* shows a plot of this mixing problem. The integrated values of contamination are plotted versus the eluate volume. From this plot one can determine the various limits to which the column can be operated even beyond the breakthrough point until a permitted predetermined maximum of contamination will be reached. These considerations introduce additional economy when ultimate purity is not required.

A case of this type is illustrated by Figure 4 where the forerun of a given column with a given crude solvent is 11 mL. The concentration of the contamination of the forerun decreases from 30 to 8 ppm. An optimum quality of 8 ppm will be received for 29 mL as the breakthrough point is assumed to appear at 40 mL eluate volume. If only the optimum quality is to be used, the capacity of the column would be 29 mL (Cap = V breakthrough − V forerun = 40 mL − 11 mL = 29 mL).

If a contamination of the solvent as high as 16 ppm is permissible, no forerun need be discarded and all of the eluate may be collected even after the breakthrough point, as long as the mixed bulk of

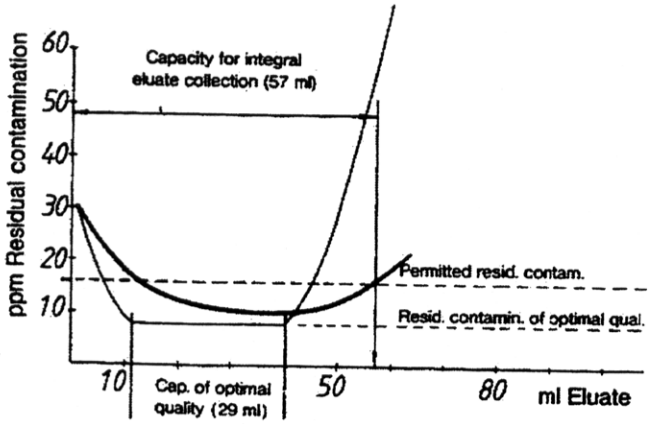

Figure 4 *Elution curve for integral eluate collection.*

the eluate would be lower than 16 ppm. The capacity of the column would then be 45 mL, i.e., 155% of the optimum quality. Whenever scale-up work is done for technical applications these aspects should be considered.

In each case, forerun and residual contamination can be minimized if the dry-packed column is initially wetted by the crude solvent as slowly as possible. For smaller columns dropwise initial application is suggested. Slow wetting of the column is necessary for the column to allow the heat of mixing to diffuse from the sorbent bed. Because the capacity is inversely proportional to the temperature, lower temperatures improve the capacity with respect to volume and at the same time improve per-

Table 2

Dependence of peroxide capacity upon moisture content

Moisture	0	1/4	1/2	1% v/v
—0—0 Cap	490	135	65	50 mL

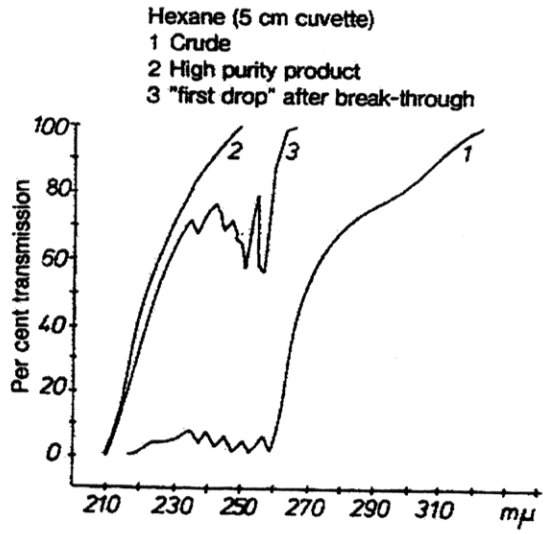

Figure 5 *Spectra of various hexane samples.*

Table 3

Dehydration of solvents

Solvent	Water content %	Water content g	Filtration through Al_2O_3 Woelm, Act. 1 Type	Column mm	Water %	Filtrate Utilizable fraction mL
Benzene*	0.07	25	basic	15	0.004	100–2500
Chloroform*	0.09	25	basic	15	0.005	50–800
Diethyl ether*	1.28	100	basic	22	0.01	200–600
Ethyl acetate*	3.25	250	neutral	37	0.01	150–350
Pyridine	0.65	30	basic	14	0.02	20–45

**Saturated with water.*

formance because even lower residual contamination will be reached.

As a general rule, after the first drop has left the column at its base, a flow of 3 mL/min can be adjusted when a column of 50 cm in length and 1.5 cm diameter is used (the flow through a 20-in. long bed should be roughly 9 mL/min. per 1-in² area). See also Figure 4, flow conditions of purification columns.

Figure 5 illustrates the spectra of crude and purified hexane and the spectrum of the first drop leaving the bed after the breakthrough point.

If more than one contaminant is present, the most polar component will determine the capacity of the bed. This is shown by the removal of peroxides from dimethyl ether (*Table 2)* where water is the second, but more polar contaminant. Therefore, the capacity for peroxides is dependent on the moisture content of the ether. The higher the moisture content, the lower the capacity for peroxides. (In a case of this type and where the water content may be substantial, it would be more economical to remove the bulk of the water first by a simpler, more economical procedure, such as distillation, and then continue with the second more sophisticated step, the removal of peroxides by the sorption process.)

The purification of liquids by percolation through a bed of active sorbent can be easily scaled up from laboratory to pilot plant volumes. A number of industrial applications have already been in operation such as the removal of stabilizers from monomers, the removal of ethanol from chloroform, the drying of ether prior to its use as a reac-

Table 4

Dehydration of solvents (II)

Solvent	Solubility of H_2O in the solvent at 25 °C (weight %)	Specific breakthrough volume (g solvent/g Al_2O_3)
n-Hexane	0.01	1450
Isooctane (2.2.4-trimethylpentane)	0.013	660
Methylene chloride	0.2	55
Chloroform	0.07	90
Carbon tetrachloride	0.01	1150
Trichloroethylene	0.025	380
Tetrachloroethylene	0.02	1440
Frigen® 113 CR (1.1.2-trichloro-1.1.2-trifluoroethane)	0.013	1770
Acetonitrile	0.1*	20
Cyclohexane	0.013	1630
DL-Dipentene	—	70
Benzene	0.065	170
Ethylbenzene	0.04	290
Cumene (isopropylbenzene)	0.03	280
Chlorobenzene	0.04	250
Bromobenzene	—	380
Decalin® (decahydronaphthalene)	0.07	1400
Diethyl ether	1.47	14
Diisopropyl ether	0.7	28
Dioxane	0.1*	25
Tetrahydrofuran	0.1*	21

**Water miscible liquid, water content of which was adjusted to the mentioned value.*

Table 5

Preparation of spectrograde solvents

Solvent	Yield (mL)	50% Transp. at wavelength*	Column
n-Pentane	250	217	40 g Silica Woelm 100-200, active
	55	217	40 g Alumina B (basic), Act I
n-Hexane	250	218	40 g Silica Woelm 100-200, active
	50		40 g Alumina Woelm B, Act I
Cyclohexane	700	233	40 g Silica Woelm 100-200, active
	80	234	40 g Alumina Woelm B, Act I
n-Heptane	500	224	40 g Silica Woelm B, active
	70	232	40 g Alumina Woelm B, Act I
	250	226	20 g Alumina Woelm B, Act I plus 20 g Silica Woelm 100-200, active
isooctane	1600	224	40 g Silica Woelm 100-200, active
	225	225	40 g Alumina Woelm B, Act I
	225	225	40 g Alumina Woelm A (acid), Act I
Carbon tetrachloride	80	280	40 g Silica Woelm 100-200, active
	4000	276	40 g Alumina Woelm A, Act I
Chloroform DAB 6	340		40 g Silica Woelm 100-200, active
	100		40 g Alumina Woelm B, Act I
Nitromethane	40	402	40 g Alumina Woelm N (neutral), Act I
Dimethyl sulfoxide	170	326	40 g Alumina Woelm B, Act I
Pyridine	30	321	40 g Silica Woelm 100-200, active
	35	332	40 g Alumina Woelm B, Act I
	30		40 g Alumina Woelm A, Act I
	25		20 g Alumina Woelm B, Act I plus 20 g Silica Woelm 100-200, active

*40 mm cuvette.

tant for Grignard reactions, and the removal of peroxides from ethers for hazard prevention prior to the distillation of the ethers. Pharmaceutical liquids also have been successfully purified, such as dimethyl sulfide and others (Germ. Pat. 1 211 169).

Tables 3, 4, and *5* show typical values of the capacities of sorbent beds for a number of solvents. These solvents were used for various analytical purposes as indicated. Optical values are compared with GC values in an application brochure entitled "Purification of solvents by adsorbents Woelm."

Percolation through a highly active bed of sorbent is a simple, versatile, and economical technique for the preparation of highly pure solvents.

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