Practical Fast Gas Chromatography for Contract Laboratory Program Pesticide Analyses*

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Abstract

An approach to shortening the analysis time for practical fast gas chromatography (GC) by using Method Translator software, which can be downloaded free from the Internet, is presented. This software simplifies the process of optimizing temperature programming while changing column dimensions, carrier gas type, and flow. Basic chromatographic theory is employed in a practical manner for adjusting column dimensions for optimal performance. In addition, electronic pneumatic control and high oven ramp rates make it easier to achieve fast analysis times without reproducibility problems. This practical approach is demonstrated using Contract Laboratory Program pesticide analytes. The factors found to be most important in decreasing the analysis time without a loss of performance are utilization of GC columns having smaller diameters and substitution of hydrogen for helium as the carrier gas.

Introduction

Though fast analyses have been a goal for many years, especially in commercial laboratories, recent work has shown a renewed interest in this area (1–3). The capabilities for fast gas chromatography (GC) have been around for many years; Figure 1 shows a chromatogram from 1988 in which the analysis time for 9 compounds is less than one second (4). Although impressive upon first glance, this is hardly a practical run for laboratories that deal with a variety of tough matrices on a daily basis. Frequently, fast analyses such as this require customized columns and adaptations added to the instrument to achieve these desired results. Because of the "fine tuning" needed and the extra cost for specialized equipment and columns, most analytical chemists have not embraced fast GC. If there was a way to shorten the GC analysis time without losing resolution and selectivity while using standard GC columns and no special instrument requirements, invariably most analysts would employ it immediately. This study introduces a practical technique to reduce a 16-min analysis to less than 7 min without a loss of resolution and with no specialized columns or major instrument variations. The compounds focused on for this work are the 22 pesticides listed in the current Contract Laboratory Program (CLP) statement of work (OLM4.2).

Column dimensions, carrier gas velocity and gas type, pressure ramping, and varied temperature ramp rates are explored in this practical approach to shortening the analysis time. The tools used are GC column theory, method translation software, HP6890 temperature-programming capabilities, electronic pneumatic control (EPC) pressure programming capabilities, and the analyst's experience.

Analysis time

This first section looks at analysis time and how it relates to the method parameters. Overall analysis time is determined by the retention time (t_R) of the last eluting compound, not including

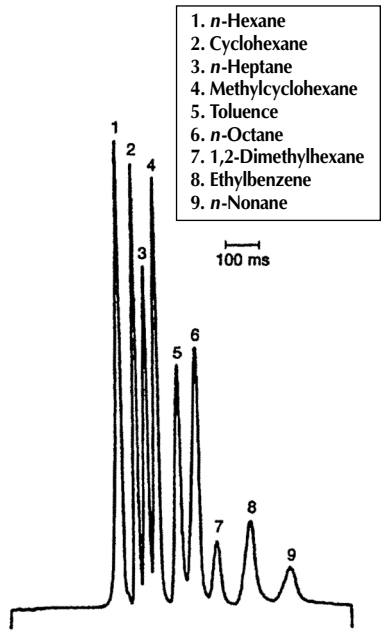

Figure 1. Fast GC (< 1 s) using a cold trap injection device showing the analysis of nine compounds from 1988. The column used was an OV-1 with a 0.3-m × 0.05-mm i.d. The carrier gas was helium, the oven was set at 72°C, and the detector used was an FID.

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any subsequent hold time after that elution. The column length (L), average linear gas velocity (μ), and retention factor (k) all have a relationship with that retention time as seen in the equation below (5):

$$t_R = (L/\mu)(k + 1) \quad \text{Eq. 1}$$

Because the relationship of the height equivalent to a theoretical plate (H) is equal to the column length divided by the column's plate number (N), L can be solved for and substituted in Equation 1, resulting in Equation 2:

$$t_R = N(H/\mu)(k + 1) \quad \text{Eq. 2}$$

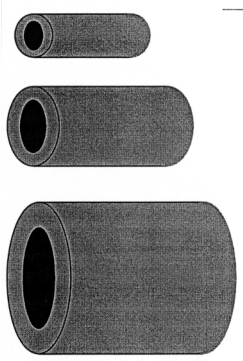
This now gives a relationship between column efficiency and the column's plate number as it relates to analysis time. If the theoretical plate height gets smaller or the average linear gas velocity gets larger, the retention time decreases. Smaller-internal-diameter columns have more plates per meter (a smaller theoretical plate height), thus shorter columns can be used without a loss of overall theoretical plates. Shorter column lengths give shorter run times; therefore, a smaller-internal-diameter column is the best choice, which is explained in detail in the next section. Also, as the gas velocity increases, obviously analysis times decrease (the carrier gas velocity and type is explored in greater depth in a later section). It is also important to note that in a temperature program run, any change in gas velocity results in a change in the temperature profile experienced by the analytes. This can greatly change the chromatographic selectivity. Changes in selectivity could mean peak switching or coelution, the last thing most analysts want. Therefore, the temperature must be adjusted concurrently with gas velocity changes in order to maintain selectivity and chromatographic resolution. It will be shown that Method Translator (Agilent Technologies, Palo Alto, CA) takes this difficult task and makes it easy.

Relationship of column diameter to efficiency and resolution

Decreasing the column internal diameter is among the most effective approaches to increasing efficiency (Table I). Because smaller-internal-diameter columns produce sharper peaks, adjacent peaks can be moved closer together without a loss in resolution. Smaller-internal-diameter columns also have lower carrier gas flow rates at the same linear velocities as larger-diameter columns. In splitless injections (as was used in this work), this lower flow can have a profound effect on the injection process, resulting in peak broadening. In order to maintain injection efficiency, a smaller volume liner was used (2-mm i.d.). Finally, smaller-internal-diameter columns have lower capacity; therefore, less sample mass may need to be injected to maintain peak sharpness and not overload the column. Instead of the normal 2-μL injection volume, a 0.5-μL injection was used. Because there was more than adequate sensitivity with the micro-ECD, there were no problems reaching method detection limits with this change in injection volume.

It should be noted that problems can occur when using extremely small diameters (< 0.18-mm i.d.). For example, required head pressures may be difficult to reach, splitless injections are very difficult to control because of the low flow rates, leaks are more prevalent in the GC system, and capacity is much lower. Therefore, caution must be exercised, but in the author's experience using the approach discussed in this study, no major adjustments or problems will occur when using 0.18-mm-i.d. columns or larger.

Table I. Typical Theoretical Plates per Meter Compared with Column Diameter. Smaller-Internal-Diameter Columns Generate More Plates per Meter



I.D. (mm)	n/m
0.05	23,160
0.10	11,580
0.18	6,660
0.20	5,830
0.25	4,630
0.32	3,660
0.45	2,840
0.53	2,060

Carrier gas type and velocity

The type of carrier gas and its velocity highly impact resolution and retention time. It must be understood that for every compound there is an optimal range of velocities and it is not the same for all compounds. Too high or too low of a carrier gas velocity results in a loss of resolution. If the velocity is too high, the compounds experience little interaction with the stationary phase, resulting in poor separation even though the peaks will be very sharp and retention time short. However, if the velocity is too low, the compounds have an abundance of interaction with the stationary phase but experience excessive longitudinal diffusion causing peak broadening and long retention times. Therefore, the analyst needs to set the gas velocity for a balance in the resolution needed and the desired analysis time.

Two very important facets of carrier gas velocity are optimum linear velocity (μ_{opt}) and optimum practical gas velocity (OPGV). μ_{opt} is defined as the gas velocity for a given compound that gives the maximum number of theoretical plates per meter of column. This gives the lowest velocity that should ever be used for any analysis. Velocities lower than this will give reduced resolution

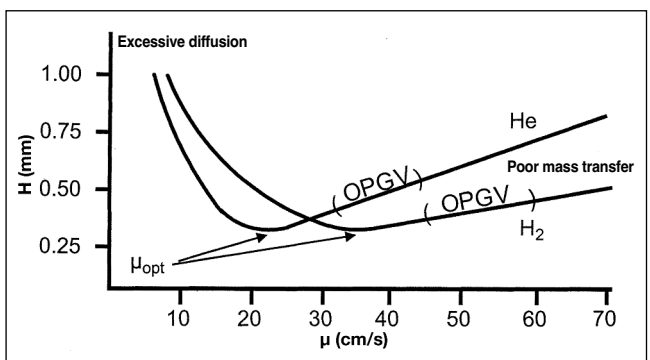


Figure 2. General van Deemter curves for helium and hydrogen carrier gases.

and increased analysis time. OPGV gives the maximum efficiency per unit of time and is usually a factor of 1.5 to 2 times that of $\mu_{opt.}$ This OPGV range is the recommended operating range. Even though a slight loss in resolution occurs (as compared with operating at μ_{opt}), the substantial reduction in retention time that occurs usually justifies the small loss in efficiency.

The relationship between the average gas velocity and efficiency is described in the van Deemter curves. The two gases represented by the van Deemter curves in Figure 2 (helium and hydrogen) are the most common carrier gases used in laboratories today. The μ_{opt} for hydrogen is at a higher average linear velocity when compared with helium, and the van Deemter curve is very flat when moving to the right of μ_{opt}. A flat curve in this region translates to very little loss in resolution with a large increase in velocity and subsequent reduction in analysis time. The extreme flatness of the hydrogen van Deemter curve makes hydrogen vastly superior for compounds eluting over a wide temperature or retention range. For these reasons, plus its lower cost compared with helium, it is easy to see why hydrogen is becoming the preferred carrier gas type by most analysts and is best suited for practical fast GC with capillary columns.

There may be reluctance to use hydrogen as a carrier gas because of its explosive nature that causes safety concerns. If proper caution is taken, hydrogen can be used with virtually no danger of reaching the explosive threshold. The explosive threshold of hydrogen in air is 4% (6). Hydrogen is very diffusive and lighter than air; therefore, it is extremely difficult to achieve a buildup of hydrogen to the point of its explosive threshold. Many authors have discussed the safe use of hydrogen as a carrier gas (7–9).

Experimental

GC method translation software

Agilent Technologies has made available a tool to translate GC methods known as the GC Method Translator (Figure 3). his is available in a free download from the Internet at www.chem.agilent.com/cag/servsup/usersoft/main.html (or use the key words "GC Method Translator" in the quick search box at the Agilent.com website). In general, the analyst inputs the original GC method parameters and this software computes a new translated temperature program and gas velocity. This is done in such a way that the chromatograms from both methods (the original and translated) look like scaled versions of each other. Specifically, the method translation software adapts the method to keep the relative retention and selectivity the same for a given set of compounds. This has great advantages because it allows the analyst to avoid the lengthy method development process, which is often necessary when switching to a new column. After original conditions of the method are entered into the software, the analyst can then change one or more of the column dimensions (i.e., internal diameter, length, film thickness, or phase ratio), carrier gas type (i.e., hydrogen, helium, argon, or nitrogen), or pneumatic set points (i.e., flow rates, head pressure, or holdup time). The software then generates a translated method (new temperature program), which will attempt to maintain the resolution and selectivity of the original method.

There are four optimization criteria (translation modes) in which the user can operate. These are "translate only", "best efficiency", "fast analysis", or "none". The first three options lock all carrier gas parameters, make the flow rate an independent parameter, and set the flow rate value according to the specific rules for each option. Selection of the none mode unlocks all carrier gas parameter cells, thus allowing the user to enter an arbitrary value in any of these cells or designate it to duplicate its counterpart in the original method. The translate only mode provides the tightest link between the properties of the original and translated methods. In best efficiency mode the software uses μ_{opt} as the gas velocity and in fast analysis mode the software uses OPGV for the gas velocity.

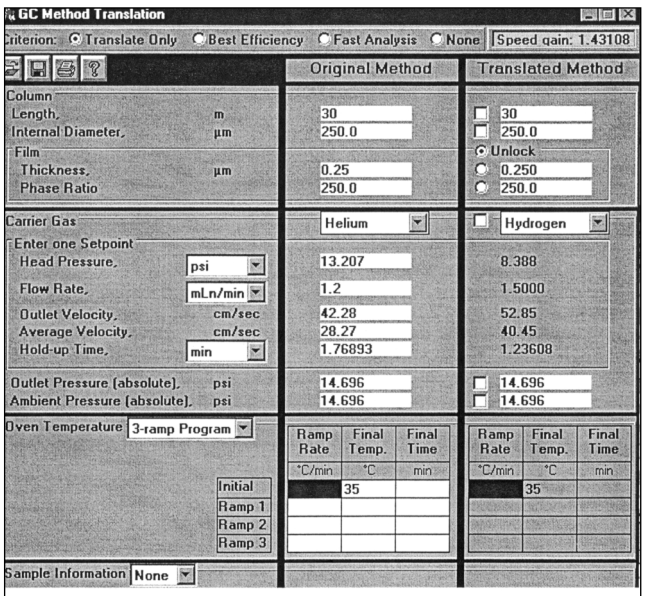


Figure 3. The Method Translation software input screen.

Results and Discussion

Original GC method

Historically for our laboratory, a typical run time has been

Table II. List of CLP Pesticide Analytes

1. TCMX	12. 4,4'-DDE
2. α-BHC	13. Dieldrin
3. γ-BHC	14. Endrin
4. β-BHC	15. 4,4'-DDD
5. δ-BHC	16. Endosulfan II
6. Heptachlor	17. Endrin aldehyde
7. Aldrin	18. 4,4'-DDT
8. Heptachlor epoxide	19. Endosulfan sulfate
9. γ-Chlordane	20. Methoxychlor
10. α-Chlordane	21. Endrin ketone
11. Endosulfan I	22. DCB

40 min for the 22 pesticide compounds in the CLP standard (Table II). This was a dual column analysis using two 30-m × 0.53-mm-i.d megabore columns with helium carrier gas (DB-5 and DB-1701 for confirmation). In an effort to improve this method, the columns were switched to 0.32-mm i.d. and the stationary phases changed to DB-17ms and DB-XLB, still using helium as the carrier gas. By referring to several application notes, help from technical support, and through a series of lengthy trial-and-error attempts, the run time was reduced to approximately 16 min (Figure 4). This still gave a coelution of two compounds (δ-BHC and heptachlor) and approximately 90% coelution of two other compounds (α-chlordane and endosulfan I) for the DB-XLB confirmation column. No coelutions were found for DB-17ms. This new method was still a vast improvement over the original

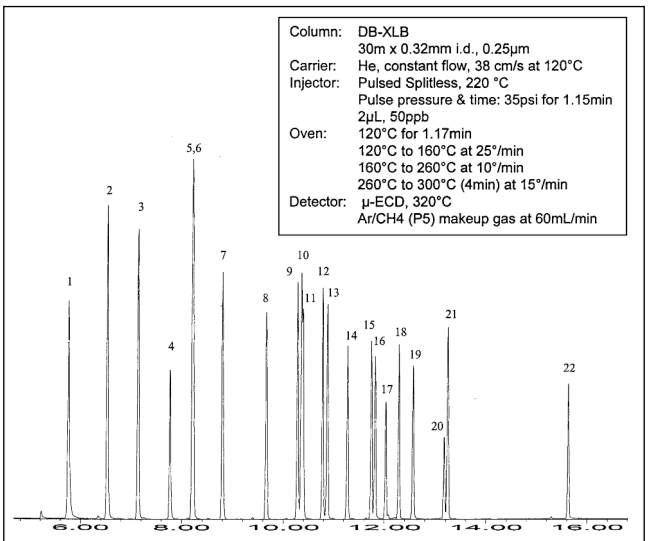


Figure 4. Chromatogram from the original "improved" method. The peak numbers are defined in Table II. There was a coelution of peaks 5 and 6 as well as a poor resolution of peaks 10 and 11.

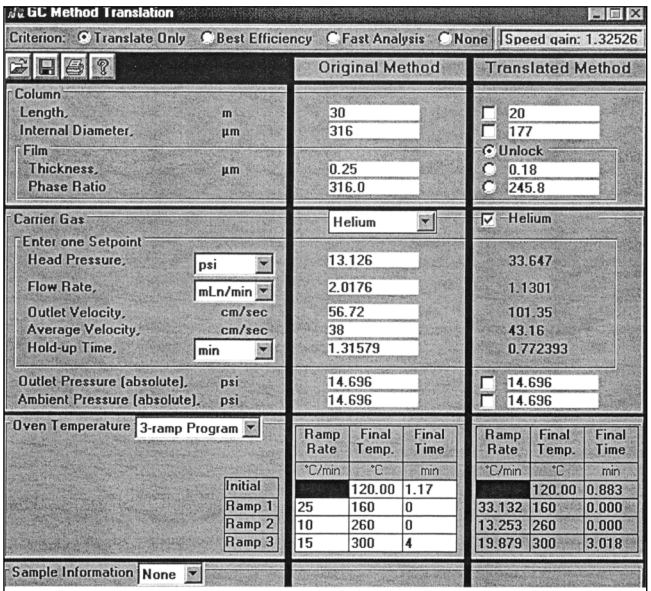


Figure 5. Method Translator's translate only mode results from inputting the new 0.18-mm-i.d. column dimensions and the original 0.32-mm-i.d. column information, still using helium as the carrier gas.

lengthy 40-min analysis. However, upon investigation using method translation software, the possibility of further improvement was recognized not only in resolution but also in run time. The new column dimensions that were chosen for "fast" GC were 20-m × 0.18-mm i.d. and 0.18-µm film thickness. Because DB-XLB gave poorer resolution as compared with DB-17ms, it became the focus of this work.

By entering the original and new column dimensions as well as the original method conditions in "translate only" mode, the software calculated the new method conditions for the 20-m column (Figure 5). It is important to note that the measured column internal diameter (0.177 mm) from the column test sheet was

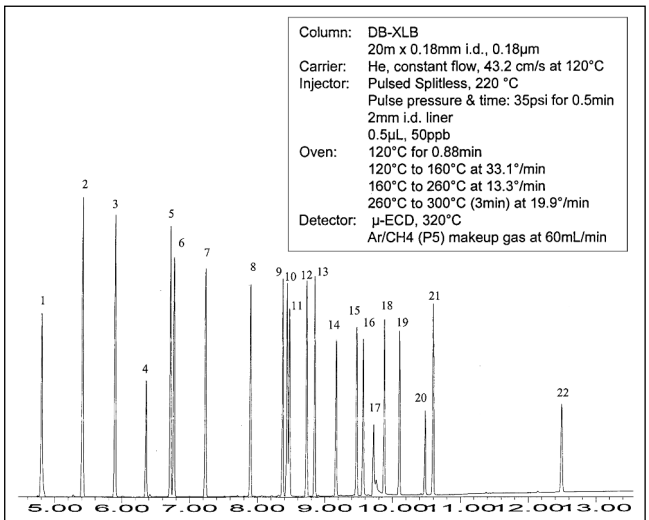


Figure 6. Resulting chromatogram for a shorter, smaller-internal-diameter column with new carrier gas velocity and temperature program settings. The peak numbers are defined in Table II. The improved resolution between peaks 5 and 6 as well as between peaks 10 and 11 should be noted.

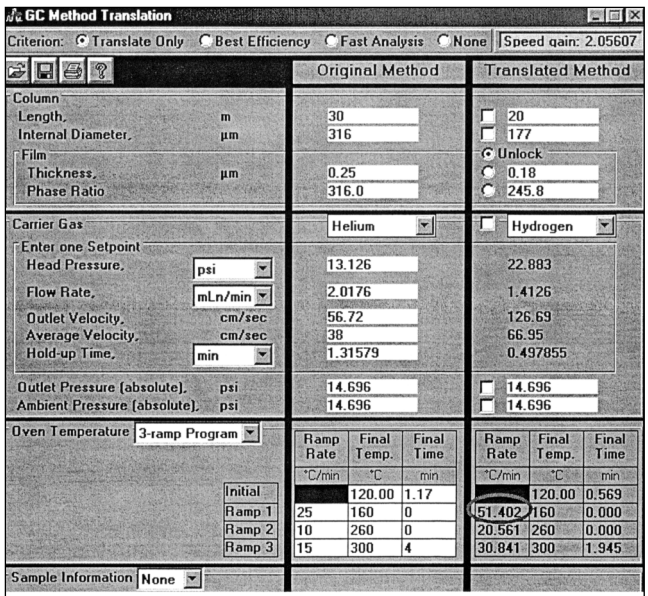


Figure 7. The Method Translation software input screen. Change of the carrier gas to hydrogen for the 0.18-mm-i.d. column dramatically increased the temperature-program rate for the first ramp. Analysis time should be half that of the original, according to the "Speed gain" given in the upper right hand of the software's input screen.

used. This gives a more accurate translation than using the nominal 0.18-mm i.d. for the calculations. The run time drastically improved from 16 min to 13 min (Figure 6) just by this change in the column internal diameter. This was a reduction of over 3 min of analysis time or approximately 19% faster. As an added bonus the resolution between δ-BHC and heptachlor became baseline resolved and the resolution between α-chlordane and endosulfan I became 80% baseline resolved. It is not intuitive, but because the peaks were coming out faster, they were sharper and more resolved. Obviously, the higher number of theoretical plates per meter of the 0.18-mm-i.d. column compared with the original 0.32-mm-i.d. column provided a vast improvement in resolution. Also, the Method Translator had done its job, because the selectivity of the compounds remained the same.

In order to improve the run time even more, hydrogen carrier gas was used. Inputting this change in gas type in the Method Translator was easily applied. The new velocity and temperature conditions are shown in Figure 7. The run time improved to 8.5 min, which is approximately half the original run time with no changes in selectivity. The chromatogram in Figure 8 shows the problem peaks still resolved. This improvement gained 4.5 min of productivity time (another 35% faster) over the previous run just by switching from helium to hydrogen carrier gas.

There was a concern when Method Translator called for a fast temperature ramp after switching to hydrogen carrier gas. The

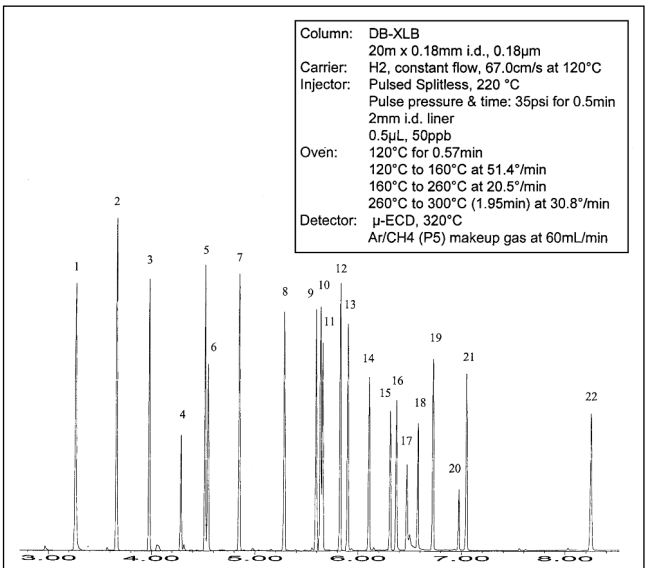


Figure 8. Resulting chromatogram with a new carrier gas type (hydrogen) and new temperature-program settings. The peak numbers are defined in Table II. Resolution was excellent and the original analysis time was induced by approximately half.

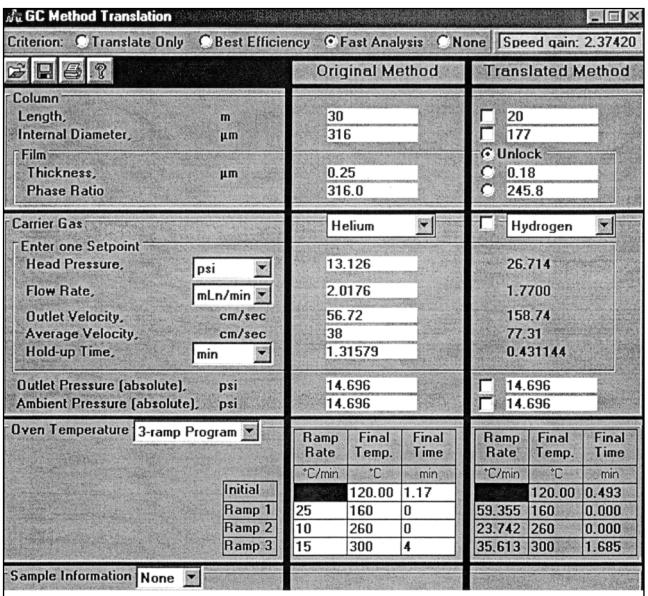


Figure 9. Method Translator's fast analysis mode (OPGV) with hydrogen carrier gas.

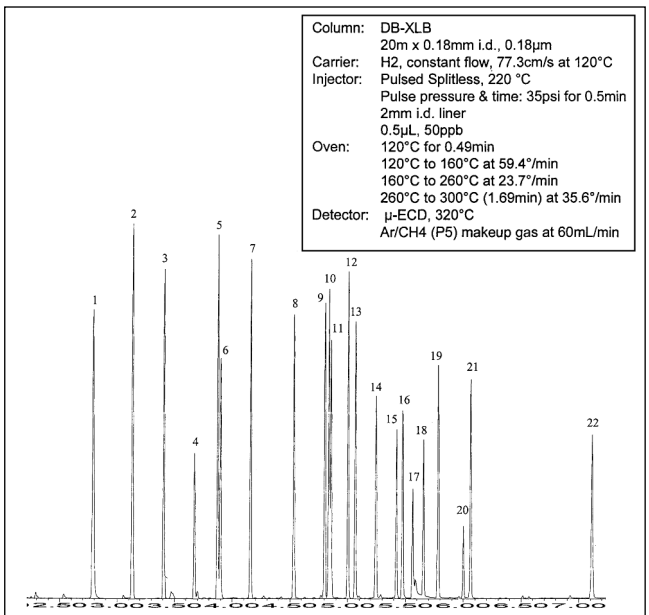


Figure 10. Resulting chromatogram using hydrogen carrier gas at OPGV with the 0.18-mm-i.d. column. The peak numbers are defined in Table II. There was a slight loss in resolution but the analysis was faster.

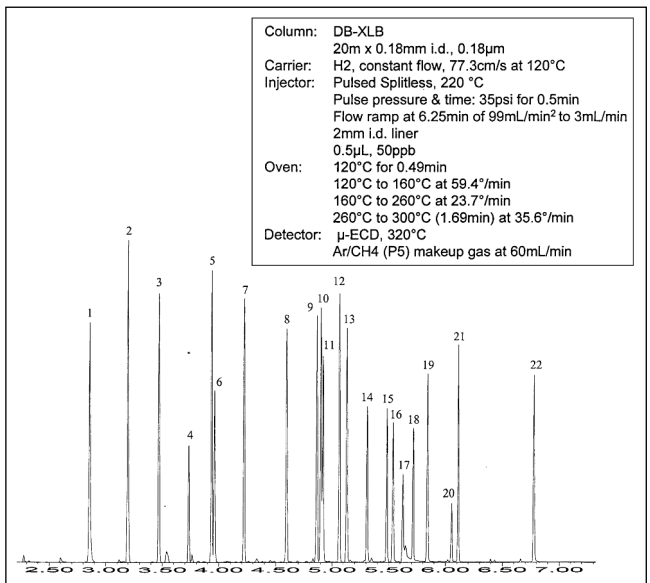


Figure 11. Resulting chromatogram after including a flow ramp after 6 min. The peak numbers are defined in Table II. Approximately 30 s was trimmed off of the analysis time.

software had calculated a 51.402°C/min ramp rate. The concern was whether the GC could handle this high ramp rate. In order to satisfy this concern, a series of 10 injections were done at these fast ramp conditions and the repeatability of the retention times was observed. All 10 runs produced the same consistent retention times out to two decimal places for all 22 compounds. Another observation was that the temperature setpoint and the actual temperature readout from the instrument tracked uniformly, alleviating any concerns. This was more than enough proof that the GC instrument could handle high ramp rates.

With this confidence in the instrument and software, even faster analyses could be attempted. If operating below OPGV (as is the case in Figure 8), the next logical step is to try the software in fast analysis mode. With hydrogen gas still used, the software calculated the conditions for a total run time of just over 7 min (Figure 9). The chromatogram in Figure 10 was the first to begin to show any real signs of loss of resolution between α-chlordane and endosulfan I. Further advances in fast analysis could have been explored if gas velocities were used from the region more to the right of the OPGV range and adjusting flows in the options of the none mode.

As a final attempt to get any extra time out of the run, flow ramping was used at the end of the run to get out the late eluting compound, decachlorobiphenyl. If the GC is equipped with computer-controlled flow the analyst has this extra degree of freedom. The chromatogram in Figure 11 shows that this allowed approximately another half minute to be trimmed off the run time (7% faster).

Figure 12 shows the final optimized dual column run for the CLP pesticide analytes with the primary column, DB-17ms included. With this total run time of under 7 min, more than twice as many samples can be analyzed as compared with the original 16-min run and almost 6 times as many as the historical method (40-min run).

Following this work, these fast analysis conditions were used routinely in the laboratory over a 9-month period with surprisingly good durability. Even though the smaller-internal-diameter columns have less capacity and are more susceptible to faster contamination buildup of the dirty samples analyzed, they lasted approximately as long as what was typically seen in the past with the 0.32-mm-i.d. columns. This was not expected and should not be used as a normal-case scenario. Twice as many samples were analyzed in that same time frame. Another thing to note is that approximately once a week routine maintenance was done in which 6 inches to 1 foot was trimmed off the inlet end of the column. Ongoing adjustments were made with the EPC to compensate for the shortening of the columns. It was not until the DB-XLB column was down to approximately 11 m before adequate resolution was no longer possible. However, at this length, resolution was still baseline for all compounds on the DB-17ms. Obviously installing guard columns would have improved the durability even more. When analyzing dirty samples, guard columns can greatly extend the life of the analytical column (10) and fewer adjustments will have to be made as routine maintenance is performed.

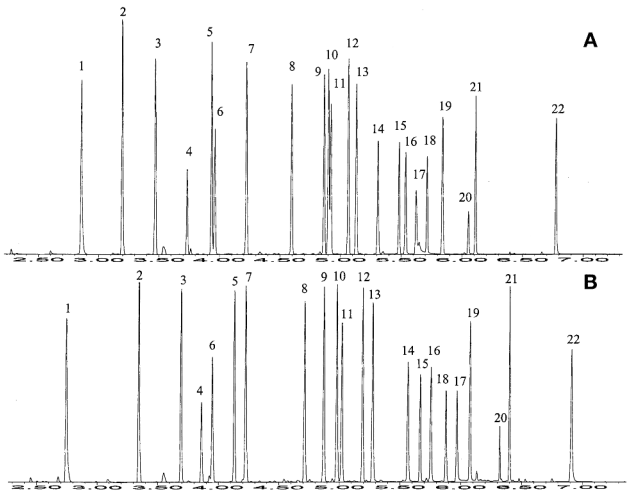


Figure 12. Final chromatograms for (A) the confirmation and (B) primary column for optimized analysis. The peak numbers are defined in Table II. There was an excellent resolution for both columns in less than 7 min.

Table III. Fast Track to Fast GC Using the Method Translator

	Same Carrier Gas Type Same Column Try **Higher Gas Velocity**	Same Column Try **Different Carrier Gas Type** (Helium to Hydrogen)	Same Carrier Gas Type Try **Smaller Column i.d.** (or other new dimensions)
Step 1	Input same column dimensions. If below OPGV, click "fast" analysis mode. If above OPGV, click "none" mode and input 10-20cm/sec faster than currently using.	In "translate only" mode, click on Hydrogen carrier and set instrument parameters with new velocity and temperature program.	In "translate only" mode input new column dimensions and set instrument with new velocity and temperature program.
Step 2	Look at new temperature program given and evaluate if equipment is capable of performing it.	Evaluate chromatogram for resolution.	Evaluate chromatogram for resolution.
Step 3	If instrumentation can perform new conditions, run and evaluate chromatogram for resolution. If instrumentation can't perform new conditions try a slower velocity until the instrument can perform the new conditions.	If plenty of resolution, click on "none" mode and try higher velocities until resolution is not adequate.	If plenty of resolution, click on "none" mode and try higher velocities until resolution is not adequate.

Conclusion

Although a one-second chromatogram may still be impractical for most laboratories, certainly cutting the analysis time in half is of some interest. Method Translator should be a standard tool for any gas chromatographer interested in speeding up the analyses done in their laboratories. Once the stationary phase is chosen for the optimum resolution of the analytes and adequate method parameters are set, this software allows for the manipulation of the column dimensions as well as carrier gas velocity and type for optimum performance. The key to obtaining this optimum performance lies in using smaller-internal-diameter columns (which often allows for shorter length columns) and employing hydrogen carrier gas in place of other more commonly used gases. These

two adjustments were found to be the most influential in the work presented. Table III sums up simple adjustments most analysts can try with little difficulty or cost. With a basic understanding of GC theory and use of these tools, fast analysis can be something practical for today's analyst.

Acknowledgments

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