New Generation of Chromatographic Separators Using the FAST Technology

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1 Abstract

Over the past 4 years the F.A.S.T. Separation Technology has brought the chromatographic separation of molasses a big step forward. The multi-profile F.A.S.T. technology offers up to 100 % better column efficiency than the classical single profile SMB technologies. The better efficiency can be used to enhance separation results like product purity and product recovery or it can simply be used to enhance throughput. The system is easy to retrofit into existing installations. New installations are possible to be built with significantly reduced resin inventory and therefore also significantly lower investment.

This paper compares the performance of the multi-profile F.A.S.T. technology to other existing systems and reviews the most recent projects in the world. Upgrading possibilities for classical SMB-systems are outlined.

2 Introduction

Chromatographic separation is a widely used tool in the sugar industry. The first industrial applications in the 60's and 70's used batch systems. D. Broughton et al.[1] patented the first SMB system in 1961, but it was initially used in petrochemicals. K. Yoritomi et al.[2, 3] developed the improved SMB system in the late 70's. In the mid 80's the simulated moving bed (SMB) was applied for the separation of molasses. In the late 80's the sequential SMB emerged, which is especially suitable for recovering three or more fractions. T. Masuda et.al.[4] presented in 1992 the New JO process, which is also capable of separating three product fractions. H. Paananen[5] covers the evolution of the different techniques in more detail in 1996, including an extensive reference list on industrial chromatography. F. Rousset and X. Lancrenon describe further development trends and new applications in 1997 [6, 7].

Recent development includes the patented two-stage[8] and multi-loop systems[9]. The combination of two or more chromatographic fractionators or the use of several circulation loops in a single system can be used to improve the efficiency of recovering multiple value-added products from the process streams of the sugar industry.

G. Hyöky et al. described in 1999 the remarkable new innovation, the multi-profile FAST separation[10], which allows much higher capacity both for new installations and for retrofitting existing chromatographic separators.

D. Paillat et.al. compared several different SMB systems in sweetener use[11].

3 Beet Based Raw Materials

Beet molasses has been widely used as raw material in chromatographic separation plants. Typically beet molasses contains on dry substance basis about 60 % sucrose, 12 % inorganic salts, 8 % organic acids, 5 % betaine, 2 % raffinose, 3 % amino acids, 0,12 % inositol and the remainder consists of hundreds of minor constituents. In addition to sugar it is also possible to recover other value-added by-products from molasses as described by H. Paananen et al.[12]. So far the most significant value-added product is betaine.

In some cases it may be preferable to use intermediate run-offs or even thick juice in the chromatographic separator. H. Paananen et al. compares the potential disadvantages and benefits [13].

4 Comparing the Different SMB Technologies

As noted above various SMB systems have been introduced over the years. The following table 1 compares 4 SMB variations, which are commercially available.

In the classical SMB all process streams flow continuously. These streams are feed (F), desorbent water (W), raffinate (R), extract (E) and circulation (C) or loop (L). In the classical SMB the system is always connected in a loop and there is no difference between the circulation and the loop steps. All steps circulate material in the system connected in a loop. A high amount of dissolved material circulates in the system. Typically the fraction outlet flows are only a small part of the high circulation flow. In molasses separation the extract flow is 5 - 10 % of the circulation flow. Thus this system has an inherently low efficiency. Figure 1 presents a typical separation profile for the classical SMB.

The system divides the components in the feed into two categories:

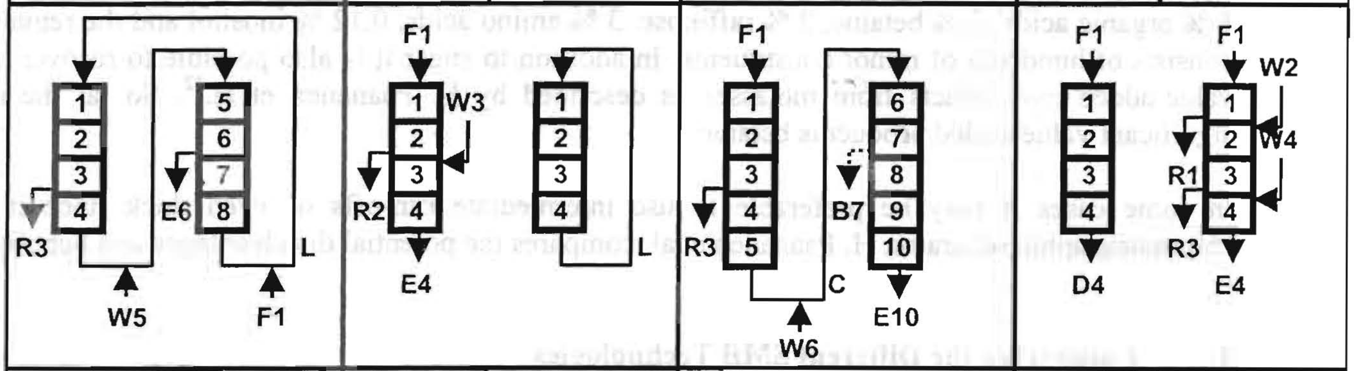
1. Components, which flow faster than the simulated, bed movement. These fast components form the so-called "raffinate" fraction.
2. Components, which flow slower than the simulated bed movement. These slow components form the so-called "extract" fraction.

This means that the classical SMB can only provide two product fractions with good recovery and purity. It is, of course, possible to combine several classical SMBs to provide separation into more than two fractions, but naturally this approach also multiplies the problems associated with the classical SMB in comparison with the more advanced SMB systems.

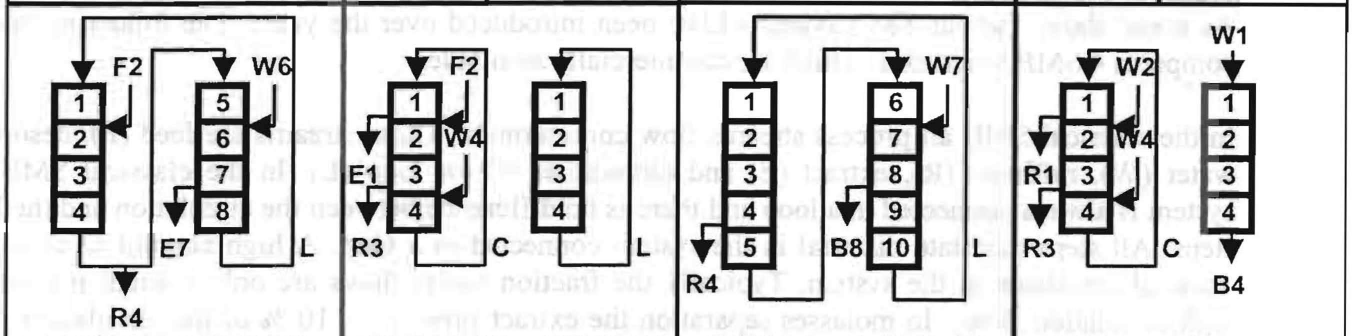
There are several suppliers for classical SMB systems. Some use relatively deep (8' - 10') resin beds and usually the system comprises eight resin compartments. The high pressure drop caused by the high circulation flow through the high resin beds limits the capacity of these systems. Therefore some suppliers believe in shallow (2' - 6') resin beds and in this case the number of resin compartments in a single system can be 10 - 20. It is, indeed, possible to reach higher capacities using shorter resin beds but the fraction purities remain poor even though the number of resin compartments is increased. The added mechanical complexity makes the systems more prone to valve and other mechanical failures. One supplier has gone so far that they have installed the compartments on a carousel in order to replace the on-off valves with a rotary valve.

TABLE 1: COMPARISON OF DIFFERENT SMB SYSTEMS

CLASSICAL SMB	IMPROVED SMB	NEW JO	F.A.S.T. 2-P
STEP 1	STEP 1 AND LOOP	STEP 1 (F+W)	STEP 1 / STEP 2



STEP 2	STEP 2 AND LOOP	STEPS 2..10 (W)	STEP 3 / STEP 4



STEPS 3 - 8 SIMILAR	STEPS 3 AND 4 SIMILAR	STEPS 3 - 10 SIMILAR	STEPS 5 - 7 DIFFERENT
CIRCULATION/FLOW RATES/PRESSURE DROP			
HIGH/HIGH/HIGH	MEDIUM/HIGH/HIGH	HIGH/HIGH/HIGH	LOW/MEDIUM/MED.
CONTINUOUSLY FLOWING STREAMS			
F, W, E, R, C=L	C	W, R, C	C
SEQUENTIALLY FLOWING STREAMS			
	F, W, E, R, L	F, E, B, L	F, W, E, R, B, D, L
TYPICAL EXTRACT PURITY FROM 60 PURITY FINAL MOLASSES			
89 %	91 %	92 %	93 %
TYPICAL SUCROSE RECOVERY FROM 60 PURITY MOLASSES IN CWT/SH.TON			
7.04 (= 100 %)	7.36 (= 105 %)	7.51 (= 107 %)	7.66 (= 109 %)
COLUMN VOLUME TO TREAT 500 TONS OF MOLASSES DAILY IN CUFT			
30 000	22 000	25 000	18 000
EQUIPMENT COMPLEXITY			
HIGH	LOW	HIGH	LOW
EQUIPMENT COST = INVESTMENT			
HIGH	MEDIUM	HIGH	LOW
CAPABILITY TO HANDLE MULTI-COMPONENT FEEDS LIKE MOLASSES			
POOR	POOR	GOOD	GOOD
NUMBER OF PRODUCT FRACTIONS WITH GOOD RECOVERY AND GOOD PURITY			
2	2	3	3 +

In table 1, I have used the deep (9') bed variant for the classical SMB, because the resin bed dimensions are roughly similar to F.A.S.T. design and it is easier to compare the systems with similar design. It is also relatively simple to convert a classical SMB to use the F.A.S.T. technology.

In the Improved SMB the streams are not flowing continuously any more. Each step is now divided into two periods: one with the F, W, R, E and C streams flowing and one with just circulation stream flowing in a loop (L). The division of each step allows much more defined fraction cut-points. Thus a.much simpler system of four beds can offer comparable sucrose recovery and better purity than the classical SMB. Feed and water are introduced to every bed and this feature makes it difficult to get more than two product fractions with good recoveries and purities. Figure 2 shows a typical separation profile for the Improved SMB system.

In the New JO process the feed point is fixed. Feed is introduced sequentially once a cycle (= F, W, R and E streams flowing). Simultaneously with the introduction of the feed a first extract fraction (E) and raffinate (R) can be taken from the system. In molasses separation this first extract would be preferably sucrose-fraction. During the other steps of the cycle only water is fed into the system and raffinate and second extract are taken out from the system. In molasses separation the second extract would typically be betaine-fraction. Each cycle comprises 10 steps (with 10 resin compartments in the system), out of which one step is the F + W step and the 9 other steps are just feeding water (W). These nine step are similar with the inlet and outlet points shifting downstream one column at a time after the step time has elapsed. Figure 3 shows a typical separation profile for the New JO system.

The above-mentioned SMB systems operate with only one profile in the system. The F.A.S.T. 2-profile process (patent pending) is an SMB with two profiles moving in the system. Figure 4 shows a typical separation profile for the F.A.S.T. 2-profile system. When two profiles are separated simultaneously, the capacity doubles. The F.A.S.T. 2-profile process is realized by using 7 - 15 different steps during each cycle (in a system with 4 compartments). The existence of two profiles is proven by the fact that two raffinate fractions can be drawn out simultaneously. For example, in step 2 raffinate fraction is taken from columns 1 and 3 simultaneously. Only the C flow is continuous in this system. Both profiles move downstream continuously. The flows of the other streams are sequential.

5 Industrial Experience

So far 8 industrial plants have been designed or converted to use the F.A.S.T. 2P system. Two new industrial plants have been specifically designed and built to use the system, and commissioned in 1999. Another large new industrial system is currently under construction.

Furthermore this new process has been selected for up-grading 5 existing industrial plants, which were initially designed for single profile SMB processes. In all retrofits significant benefits have been achieved.

For example, we recently converted 2 classical SMBs in Japan to use the F.A.S.T. 2-P system. The following improvements were noted.

1. Betaine recovery as third product fraction with 85..90 % recovery
2. The purity of sucrose fraction increased by 3 .. 5 %-units
3. The recovery of sucrose increased by 2..4 %-units to correspond with sugar in the bag recovery of 8,8 cwt/t calculated from 60 purity molasses.
4. The overall capacity increased by 10..15 % (for both converted units together, and this increase is limited by bottlenecks elsewhere in the beet sugar plant)
5. Pressure drop problems disappeared

The conversion work included some minor piping changes plus, of course, the equipment needed to handle the new product fraction: betaine. The separation columns and the resin remain the same. The main change was the new cycle program with the steps needed to generate the two profiles in the old systems. Thus we can note that with exactly the same column hardware the performance increase is tremendous. Betaine separation as a third fraction would normally require about 15..20 % more column capacity. In addition to this the throughput increased by 10..15 % and both the sucrose recovery and purity increased.

6 Conclusions

The most recent F.A.S.T. 2-profile separation technology provides fundamental benefits in terms of molasses separation capacity, multiple-fraction separation, and product purity. These benefits are not limited to new molasses separation plants, but can also be extended to existing deep bed classical SMBs . The significant improvements obtained after retrofitting to the FAST 2-profile technology make such an up-grade a very attractive investment.

It can also be a definite option to resolve the pressure drop difficulties, which plague so many of the existing SMB chromatographic separation systems.

7 Figures

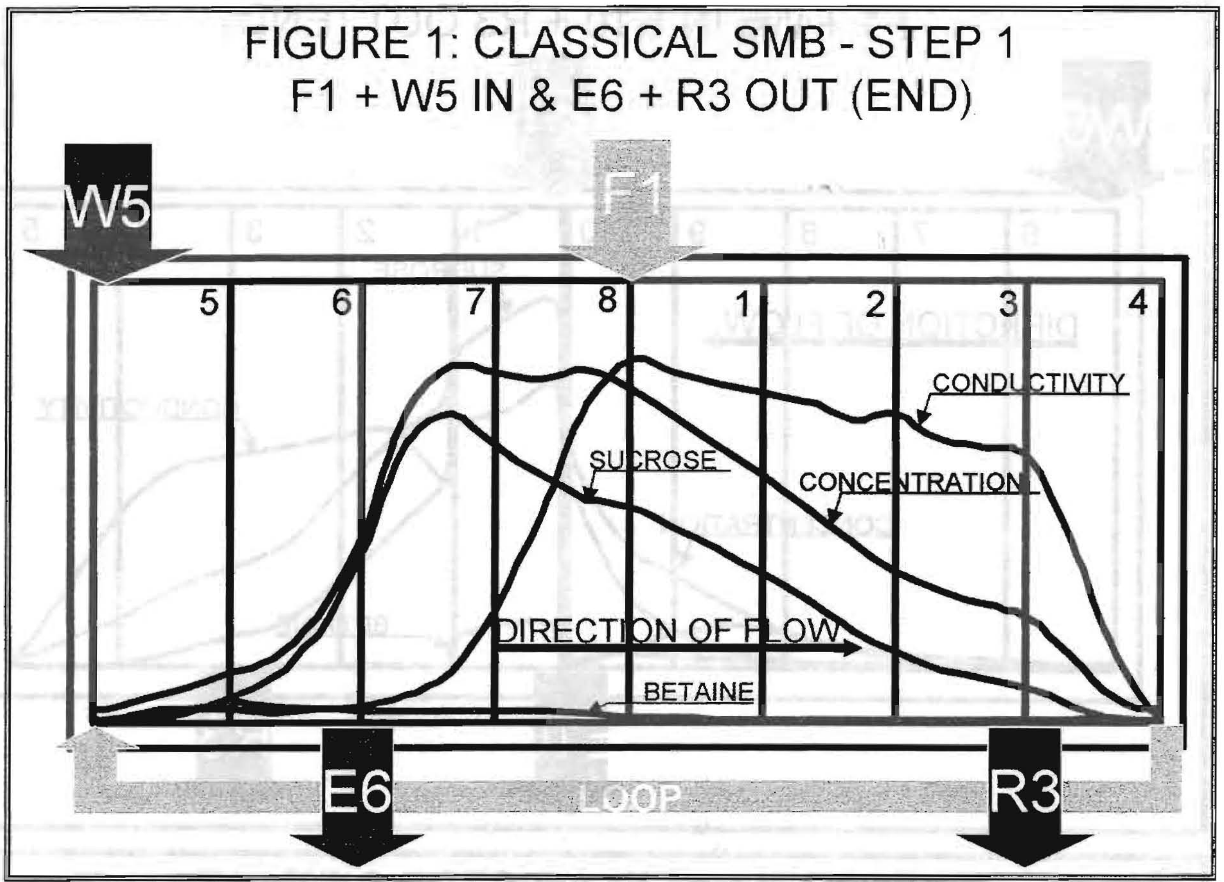


FIGURE 1: CLASSICAL SMB - STEP 1
F1 + W5 IN & E6 + R3 OUT (END)
W5
F1
5
6
7
8
1
2
3
4
CONDUCTIVITY
SUCROSE
CONCENTRATION
DIRECTION OF FLOW
BETAINE
E6
LOOP
R3

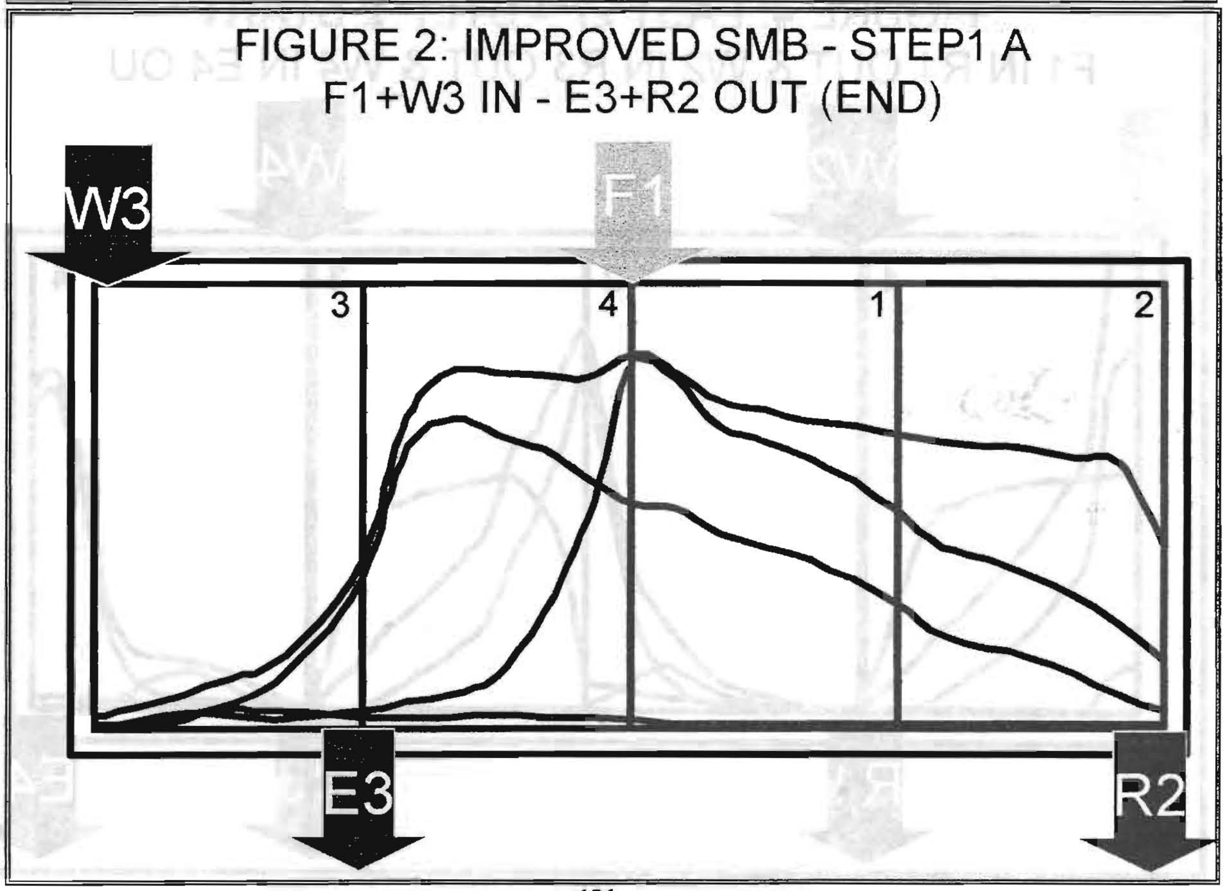


FIGURE 2: IMPROVED SMB - STEP1 A
F1+W3 IN - E3+R2 OUT (END)
W3
F1
3
4
1
2
E3
R2

FIGURE 3: NEW JO - STEP 1
F1 + W6 IN E10 + R3 OUT (END)

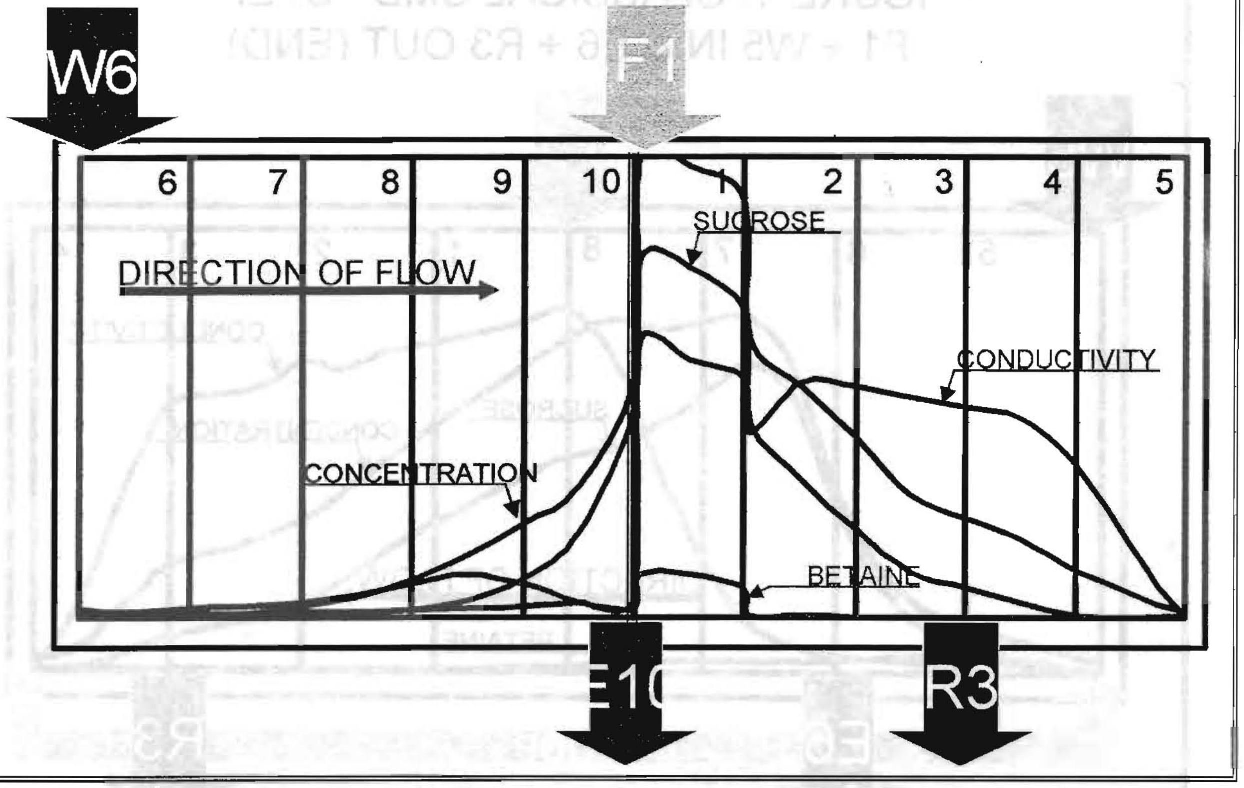
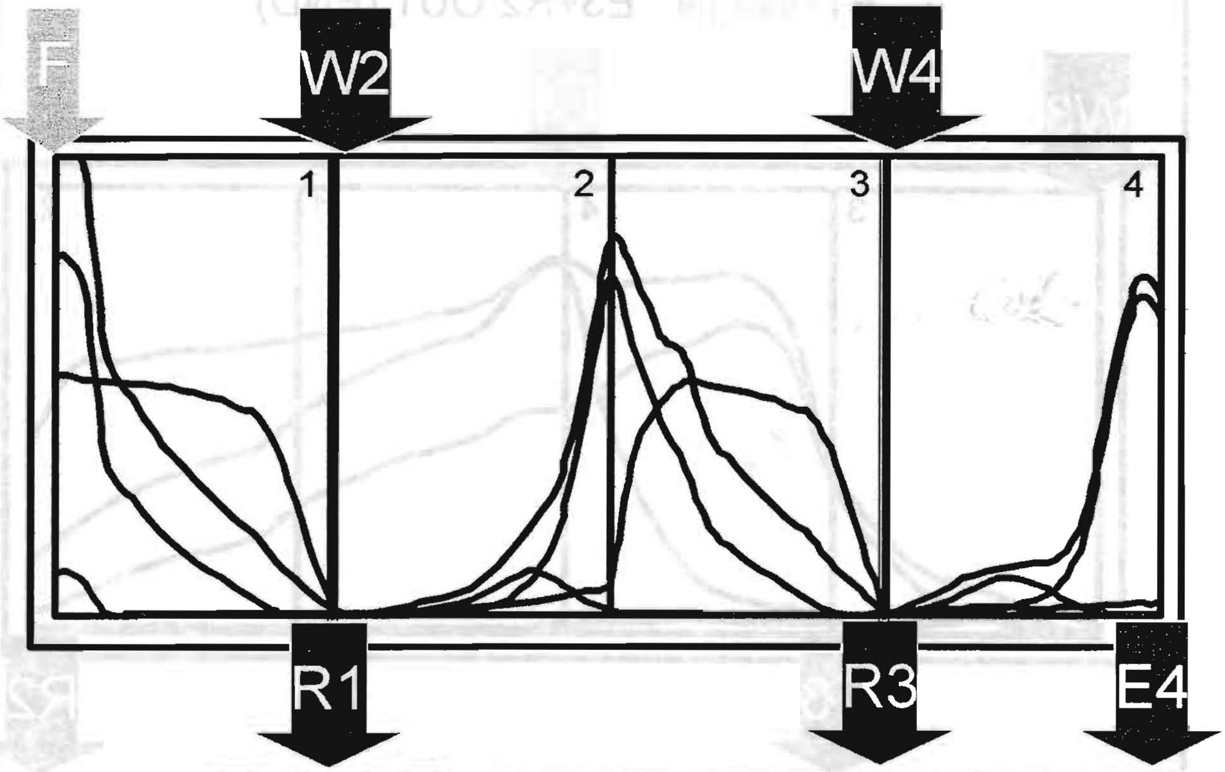


FIGURE 4: FAST 2P - STEP 2 START
F1 IN R1 OUT & W2 IN R3 OUT & W4 IN E4 OUT



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