

APPENDIX B2 TRACER BEHAVIOR DURING INJECTION-BACKFLOW
TESTING AT THE RAFT RIVER GEOTHERMAL SYSTEM

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INTRODUCTION

During the past decade, considerable emphasis has been placed on reactions which occur between geothermal fluids and their host rocks. As a result of numerous investigations a number of specific water-rock interactions have been suggested, primarily involving silicate minerals, as controls on the chemistry of geothermal fluids (i.e. Ellis and Mahon, 1977). These reactions are the basis for the cation geothermometers currently being used to estimate subsurface reservoir temperatures from fluid chemistry.

More recent investigations, however, such as those of Potter and others (1982) have shown that, at least for the Na-K geothermometers, specific reactions involving feldspars are clearly an oversimplification of the actual water-rock reactions which govern the chemistry of these fluids. These studies indicate that water-rock interactions are not yet well understood.

The chemical data from the Raft River injection program provide an unusual opportunity to examine the mechanisms of water-rock interactions in a well characterized but complex multicomponent system. This investigation has been divided into two parts. The first part, presented here, contains recovery curves for eleven elements. The reactivity of these elements is then discussed based on their fractions of recovery. Part II will include a detailed description of elemental gains and losses during each injection test and an assessment of possible reactions responsible for these changes.

SAMPLE COLLECTION AND CHEMICAL ANALYSIS

Methods of sample collection and analysis have been presented by Capuano (1983). The results of these analyses have been compiled by Large (1983).

TRACER RECOVERY

Nine injection-backflow tests were conducted on well RRG5 at the Raft River geothermal site. A summary of the test parameters are included in a companion report by Capuano (1983) and in Table 1. For each of these tests Capuano (1983) developed a generalized recovery curve that represents only mixing of the injectate with reservoir solution. Recoveries of the conservative tracers, Na, K, and Cl, were used to develop these curves. These conservative tracers are relatively unaffected by water-rock reactions during Raft River testing.

The generalized recovery curves for the tests discussed in this report, 2A-2, 2C and 2D, are shown in Figure 1. Recovery curves for the natural and artificial tracers, Ca, Mg, Fe, SiO₂, Sr, Li, B, F, SO₄, I and Na₂Fluorescein, for these tests are included in Appendices B2-1 through B2-3. These curves were calculated using the methods discussed in Capuano (1983). Comparison of these recovery curves with the generalized recovery curves for each test, allows prediction of elemental gains and losses resulting from processes other than mixing. These processes can include adsorption or desorption, dissolution or precipitation, ion exchange, and for the tracer dye, Na₂Fluorescein, thermal instability.

WELL BORE RECOVERY

The effects of water-rock reactions and mixing are minimal in solution confined to the well bore. Therefore the tracer content of the final solution

injected into the well bore (7.1×10^4 liters) should equal the tracer content of the initial solution removed from the well bore. This comparison provides a unique opportunity to evaluate the overall quality of data collected for each test. For example, errors in chemical analyses or in estimation of flow rates, mixing in the well bore and accidental flow during quiescence periods are all potential sources of error that can be evaluated.

The fractions of well bore recovery for all the continuously injected tracers from tests 2A-2, 2C and 2D are listed in Table 2. Ca, Sr, Li, I and Na₂Fluorescein generally show good well bore recoveries with an error of 6% or less. Considering the analytic precision for these elements, which ranges from 1 to 10% (Capuano, 1983) and the probable 5% or greater error on the flow rate determinations, these comparisons are surprisingly close. B has only 1% error on well bore recovery from test 2C. However, from test 2A-2 the error is up to 13%.

Both Mg and Fe show very poor well bore recoveries from test 2C and 2D. MgCl₂, with Fe impurities, was added as an artificial tracer during these tests. The MgCl₂ used was industrial grade and, therefore, contained solid impurities that clogged the tracer filters causing irregular injection concentration. Analyses of the injected solution were too widely spaced to accurately calculate the injection masses, thereby, accounting for the irregular injection rates. This resulted in the poor comparison between well bore injection and recovery.

SiO₂ showed a loss, ranging from 12 to 45%, upon recovery from the well bore for all three tests. This is possibly the result of silica deposition in response to decreased solution temperatures during tests. The remaining two elements Fe and SO₄ were analyzed on a much wider spacing than the other nine elements and therefore errors in well bore recoveries are probably the result

of this wide spacing. Additional analyses are scheduled for all elements having well bore recovery errors greater than 6% to determine the cause of these discrepancies.

TRACER GAINS AND LOSSES

The total masses of the 11 elements considered in this study both injected and backflowed were calculated using the methods of Capuano (1983). The ratio of tracer recovered as compared to the amount injected and the relative gains and losses for these elements are listed in Table 3.

Gain or loss of less than 10% have been considered to be within the error of data collection and analysis. For a more accurate evaluation it is necessary to evaluate gains and losses on the basis of individual sample concentrations. This type of evaluation is planned for the second part of this report.

It is apparent that tracer reactivities were affected by the composition of the artificial tracer added to solution (Table 1). For test 2A-2, NaI was added continuously to the injectate. During test 2C MgCl₂ and Na₂Fluorescein were added continuously. During test 2D 2 slugs were injected, one containing NaI and Na₂Fluorescein, the other Borax (Na₂B₄O₇·5H₂O) and Na₂Fluorescein. In addition to these two slugs, MgCl₂ was injected continuously during the final 6 hours of injection. Test 2C, with MgCl₂ injected as a continuous artificial tracer, showed an interesting example of water-rock reactions. The recovery solution from test 2C was depleted in Mg and SiO₂ and enriched in Ca, Fe, Sr, Li, B, F and Na₂Fluorescein. Examination of the concentration vs. time curves for Mg, Ca and the conservative tracer Cl allows a preliminary evaluation of the reactions taking place (Figure 2). Mg is depleted by approximately 40 mg/liter (1.65×10^{-3} moles/liter) and Ca enriched by approximately 64

mg/liter (1.60×10^{-3} moles/liter). The Ca enrichment gives initial Ca concentration in the backflow solution up to 40 mg/liter higher than Ca measured in either the injected RRGP3 water plus tracer or RRGP5 reservoir water. The molar loss of Mg is almost equivalent to the molar increase in Ca suggesting cation exchange of Ca for Mg. One likely source of Ca near the well bore is the large quantities of cement or mud injected into the formation around well RRGP5 during drilling and hydrofracturing operations.

Sr, Li and Fe all show enrichments in the backflow solution similar to Ca, but of a smaller magnitude. This suggests that Mg also exchanged, however in relatively small quantities, for these elements.

In contrast to test 2C recoveries, Ca and Li recoveries from tests 2A-2 and 2D had relatively insignificant gains and losses of less than 9%, Mg was enriched in 2D backflow solution and recovered in undetectable amounts in 2A-2 backflow. Similar to test 2C Sr was also increased in 2A-2 and 2D backflow, and Fe in 2D backflow, but not by the same magnitude.

SO_4 was recovered from test 2C with no gains or losses, however, from both test 2A-2 and 2D it was depleted in the recovered solution.

The artificial tracer iodide, injected during tests 2A-2 and 2D, was depleted from both recovery solutions by up to 20%. Na_2 Fluorescein, however, was recovered in excess of 150% from test 2C. Rather than being a result of reactivity this excess recovery is believed a result of analytic errors or irregular tracer injection rates. This is because there is no source for Na_2 Fluorescein in the reservoir rock. However, because Na_2 Fluorescein was injected during an earlier test 2A-1, some Na_2 Fluorescein may have remained in the well bore. The quantities involved were relatively small when compared to the excess recovered in test 2C. In contrast, Na_2 Fluorescein recovery from test 2D suggested relatively no gains or losses.

The remaining elements B, F and SiO_2 appeared to be affected by water-rock reactions, independent of the composition of the artificial tracer. B and F acted similarly and were recovered in excess from all three tests. SiO_2 showed a relatively small loss of 10% from test 2A-2 and was depleted in excess of 90% from test 2C and 2D recovery solutions. These losses are probably the results of silica deposition in response to decreased reservoir temperatures during injection and cooling of the backflow solution.

CONCLUSION

It is apparent that while the elements Na, K and Cl are relatively unreactive during Raft River testing, many of the other natural and artificial tracers were not conserved. These reactive elements include Ca, Mg, Fe, SiO_2 , Sr, Li, B, F, SO_4 , I and $\text{Na}_2\text{Fluorescein}$. To understand the reactions resulting in the relative depletions or enrichments of these elements a detailed comparison of individual sample concentrations is needed. A preliminary evaluation of the recovery curves, however, suggests the following reactions occur:

1. When Mg is added to the injection solution in large quantities as an artificial tracer it exchanges with solids in the reservoir for Ca and minor amounts of Fe, Sr and Li.
2. SiO_2 is extracted from the injection solution, probably as a result of silica deposition in response to decreased temperatures during testing.

In comparison to the elemental gains and losses, the general conservative character of Na, K and Ca (except when Mg is added a tracer) indicates that feldspar and other silicate reactions are not significant short term mechanisms for controlling fluid composition. This supports the findings of

Potter and others (1982) in which they concluded that reactions involving feldspars are probably not the single most important factor in controlling the chemistry of geothermal fluids.

REFERENCES

- Capuano, R. M., 1983, Raft River injection testing recovery curves: Earth Science Laboratory, University of Utah Research Institute Report, in press.
- Ellis, A. J., and Mahon, W. A. J., 1977, Chemistry and Geothermal Systems: Academic Press, N.Y., 392 p.
- Large, R. M., 1983, Hydrothermal injection program phase I test data index: EG&G Idaho Inc., Internal Report RE-PB-83-015.
- Potter, J., Dibble, W., Parks, G., and Nui, A., 1982, Improvements in geothermometry: Dept. Geophysics, Stanford University, Final Tech. Report, DOE Contract DE-FC-07-80-ID-12147, 61 p.

TABLE 1. RAFT RIVER INJECTION TESTS

TEST NO.	VOLUME INJECTED ^a (liters)	QUIESCENCE TIME (hours)	NATURAL TRACER (from well)	ARTIFICIAL TRACERS		SOLUTION INJECTED BEHIND SLUG (liters)
				CONTINUOUS	SLUG ^e	
<u>2 SERIES</u>						
A-1	0 ^b	0	RRGE3	NaI, NaBr, MgCl ₂ , Borax ^f		
A-2	6.3 x 10 ⁴	0	RRGE3	NaI		
C	1.5 x 10 ⁶	0	RRGE3	MgCl ₂ , Fluor. ^{f,9}		
D	3.3 x 10 ⁶	0	RRGE3	MgCl ₂ ^c , Rhod. ^{d,f}	NaI, Fluor. Borax, Fluor.	3.3 x 10 ⁶ 2.5 x 10 ⁶
<u>4 SERIES</u>						
A	1.1 x 10 ⁴	28	RRGE3	NaI		
B	0.72 x 10 ⁴	2	RRGE3	NaSCN, Fluor.		
C	0.61 x 10 ⁴	12	RRGE3	NaI		
D	0.99 x 10 ⁴	50	RRGE3	NaBr, Fluor.		
<u>5 SERIES</u>						
5	1.3 x 10 ⁷	80	RRGE3		NaI, NaBr, Fluor., Rhod.	1.3 x 10 ⁷

^a This is only the volume that entered the formation. It does not include the 7.1 x 10⁴ liters injected into the well bore.

^b This was a well bore test only. The 3.3 x 10⁴ liters injected into the 7.1 x 10⁴ liter well bore did not enter the formation.

^c Injected continuously during final 6 hrs. of injection.

^d Injected continuously during final 2 hrs. of injection.

^e Slug injected during 10 minute period, approximately 5700 liters.

^f Borax = Na₂B₄O₇·5H₂O, Fluor. = Na₂-Fluorescein, Rhod. = Rhodamine-B.

⁹ Injected continuously for 3 hrs., starting at 3.5 hrs. before the end of injection.

TABLE 2. Ratio of the Mass of Tracer Recovered vs. Mass Injected into the Well Bore.

TRACER	TEST		
	2A-2	2C	2D
Ca	.98	1.06	.99
Mg	-- ^b	.73	13.04
Fe	-- ^b	1.22	2.16
SiO ₂	.88	.78	.55
Sr	.99	1.02	.99
Li	.99	1.02	.98
B	.87	1.01	-- ^c
F	.94	.94	.91
SO ₄	.79	1.01	.54
I	.94	--	--
FLUOR. ^a	--	.96	--

^a FLUOR. = Na₂Fluorescein.

^b Concentrations below detection limits.

^c Injected as tracer slug.

TABLE 3. Rates of the Total Mass of Tracer Injected vs. Mass Recovered and Percent Gains and Losses

TRACER	FRACTION INJECTATE RECOVERED			% GAIN OR % LOSS ^d		
	TESTS			TESTS		
	2A-2	2C	2D	2A-2	2C	2D
Ca	.98	1.12	.70	-1	78	6
Mg	-- ^c	.38	.92	--	-46	39
Fe	.70	4.71	2.81	-29	658	326
SiO ₂	1.09	.04	.06	10	-94	-91
Sr	1.15	.90	.73	16	43	11
Li	.90	.76	.68	-9	21	3
B	1.90	1.15	.79	92	83	20
F	1.78	1.33	.86	80	111	30
SO ₄	.61	.63	.23	-38	0	-65
I	.87	--	.53	-18	--	-20
FLUOR. ^a	--	1.63	.70	--	159	6
INJECTATE ^b	.99	.63	.66			

^a FLUOR. = Na₂Fluorescein.

^b Ratio of injectate recovered taken from Capuano (1983).

^c Concentrations below detection limits.

^d Positive value is percent gain, negative value percent loss.

GENERALIZED MIXING CURVES RAFT RIVER

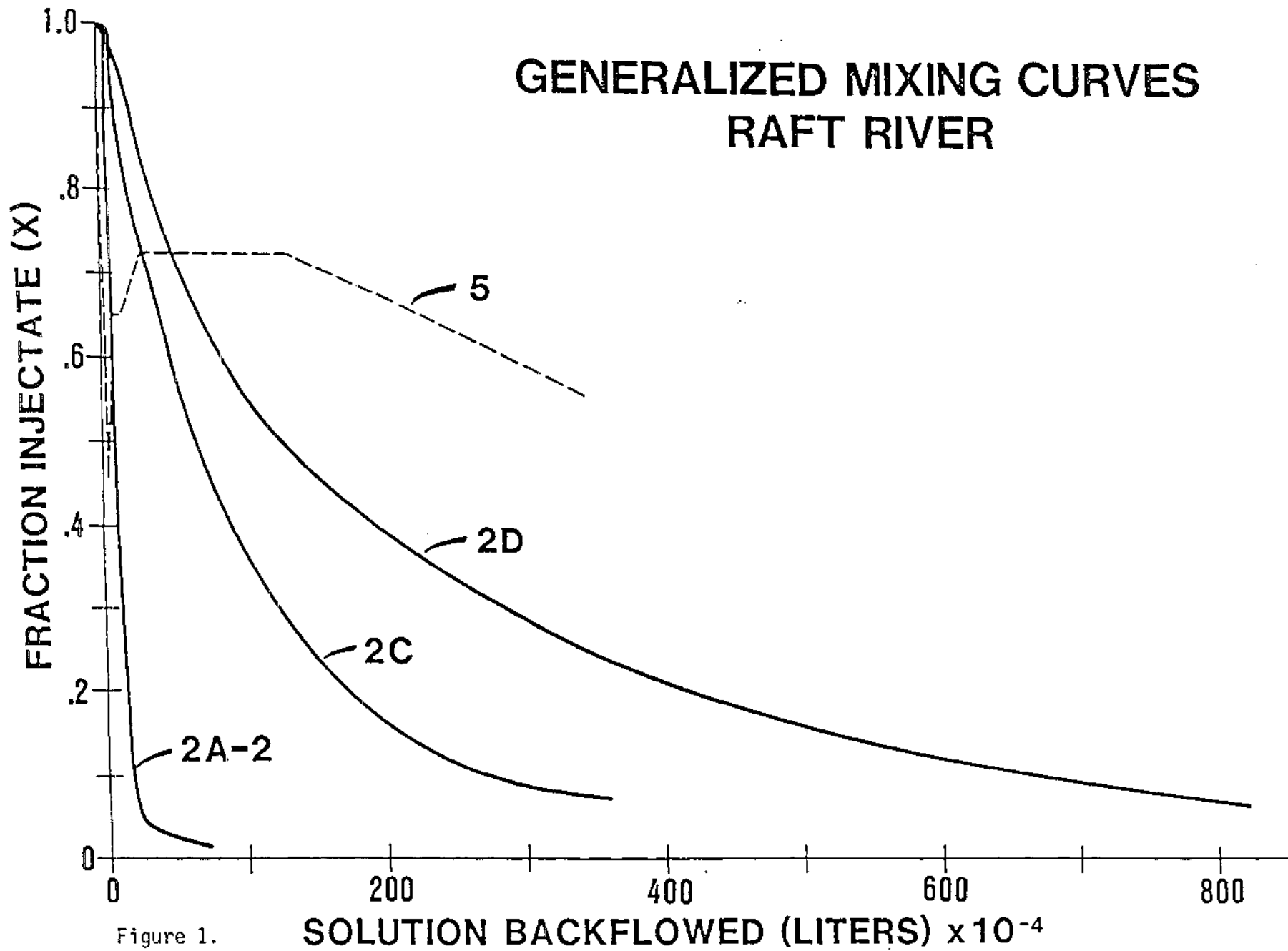


Figure 1.

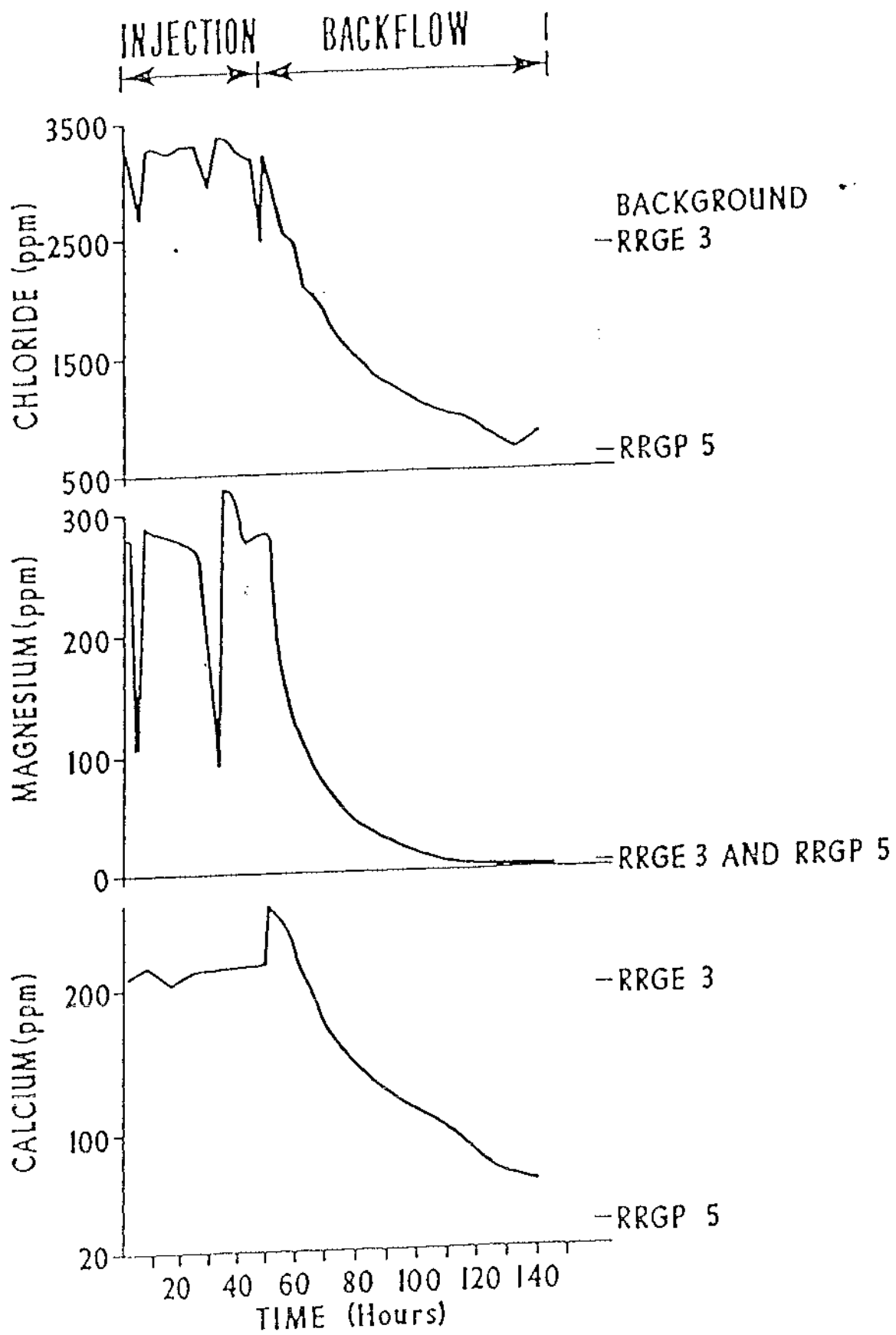


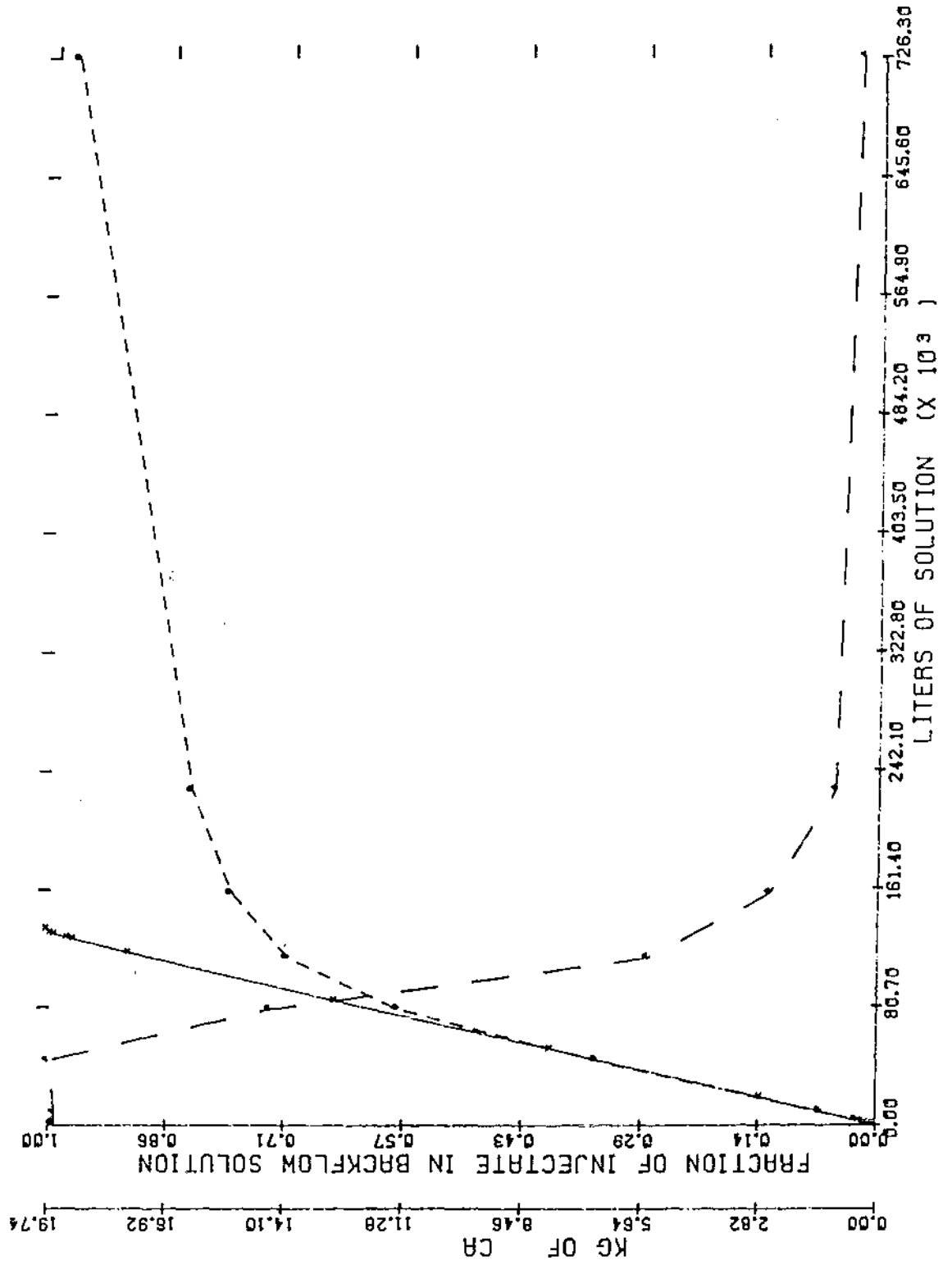
Figure 2.

APPENDIX B2-1

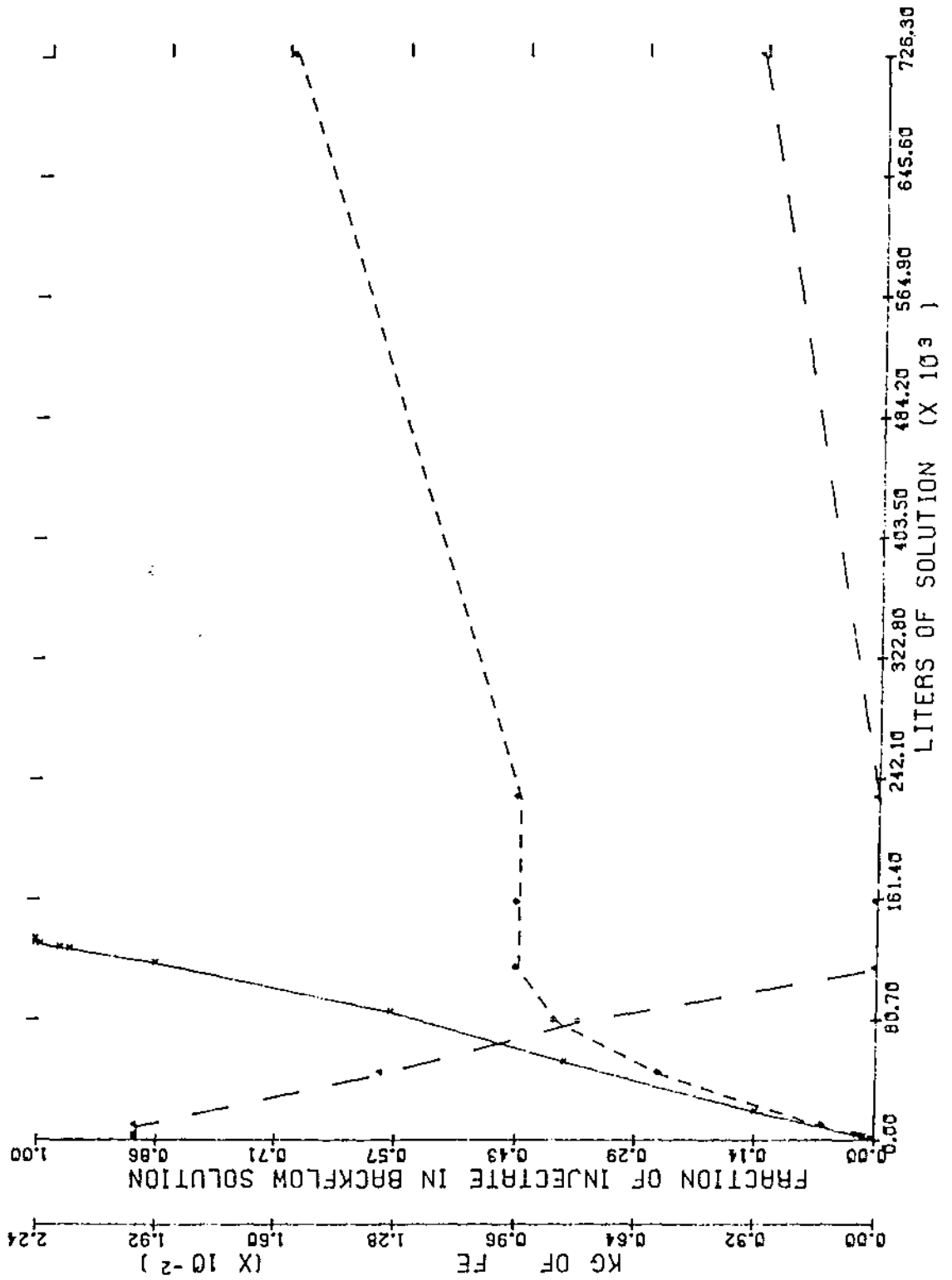
Recovery Curves Test 2A-2

For the recovery curves in this Appendix a long dashed line connecting triangles represents the fraction of injectate in the backflow solution, the solid line connecting x's represents the Kg's of the element injected and the short dashed line connecting hexagons represents the Kg's of the element backflowed.

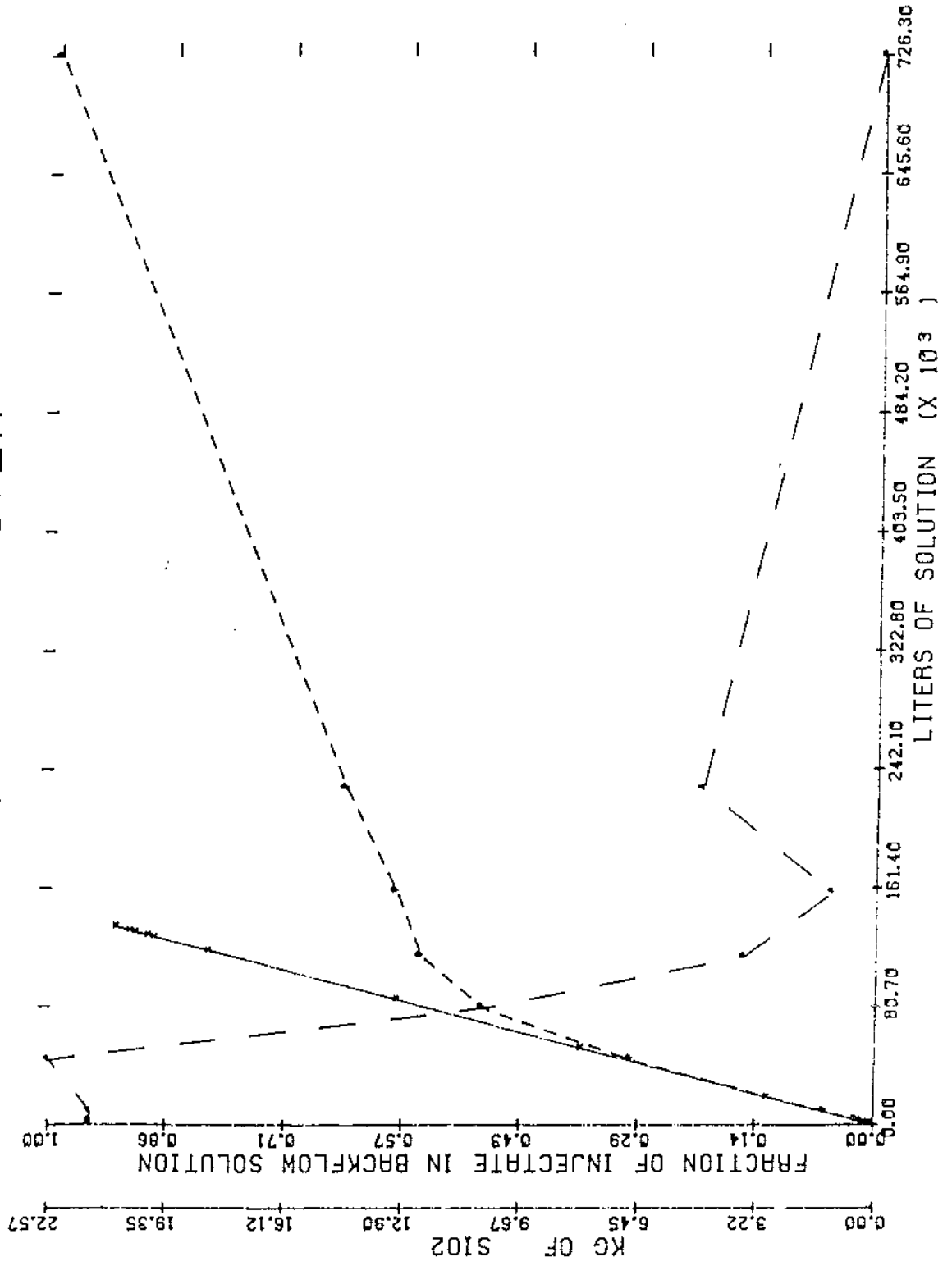
TEST 2A-2, RAFT RIVER



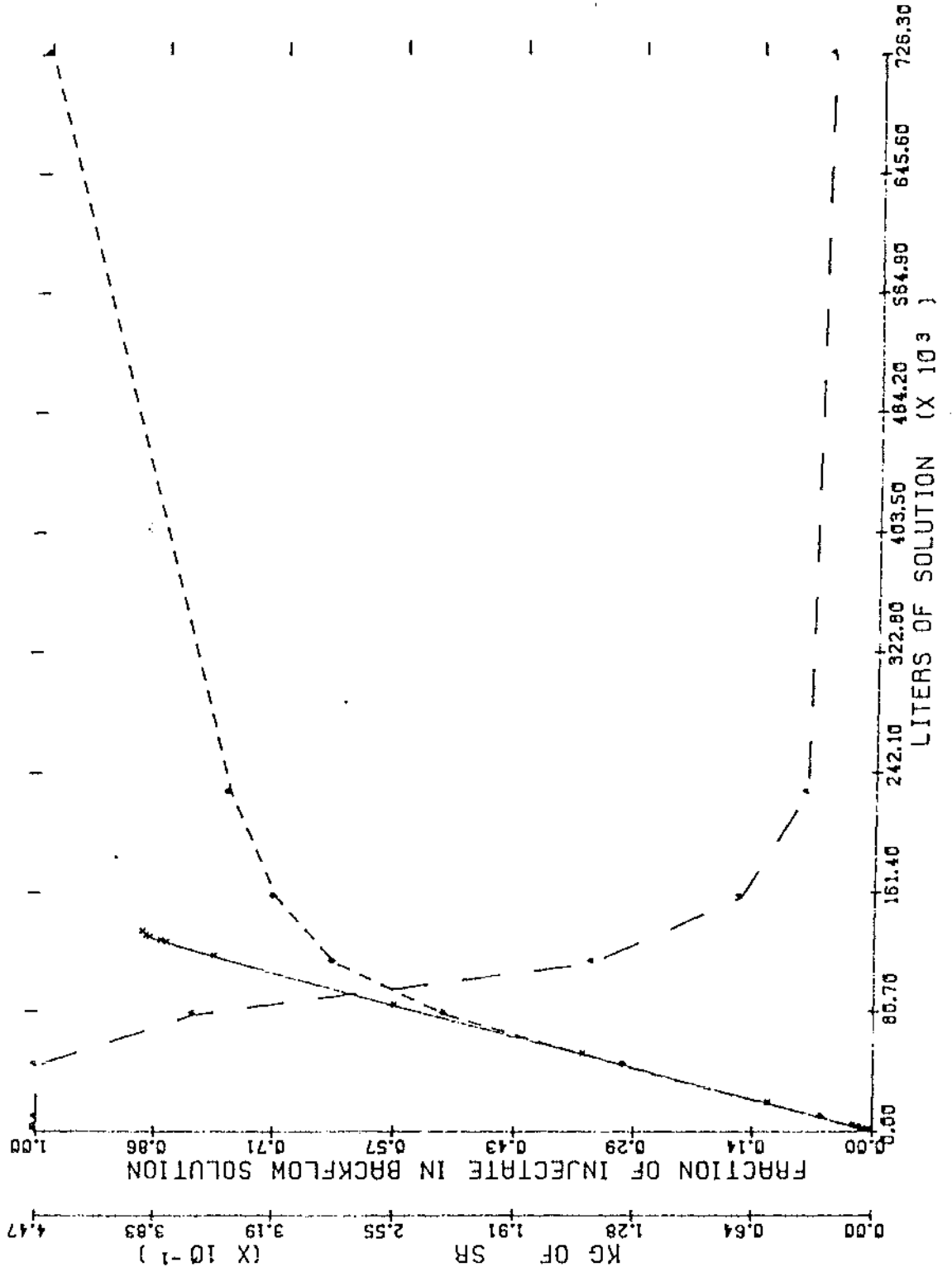
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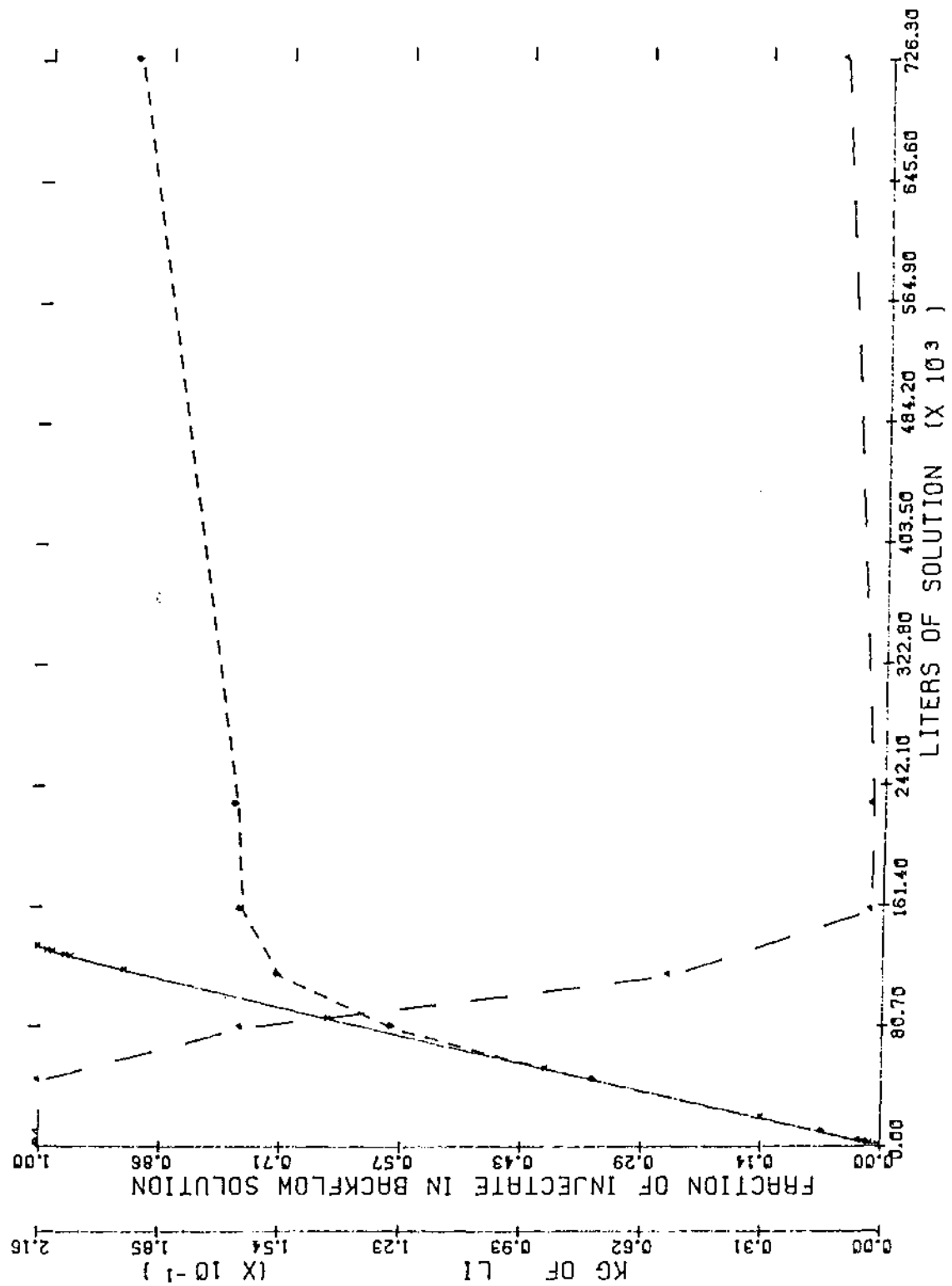
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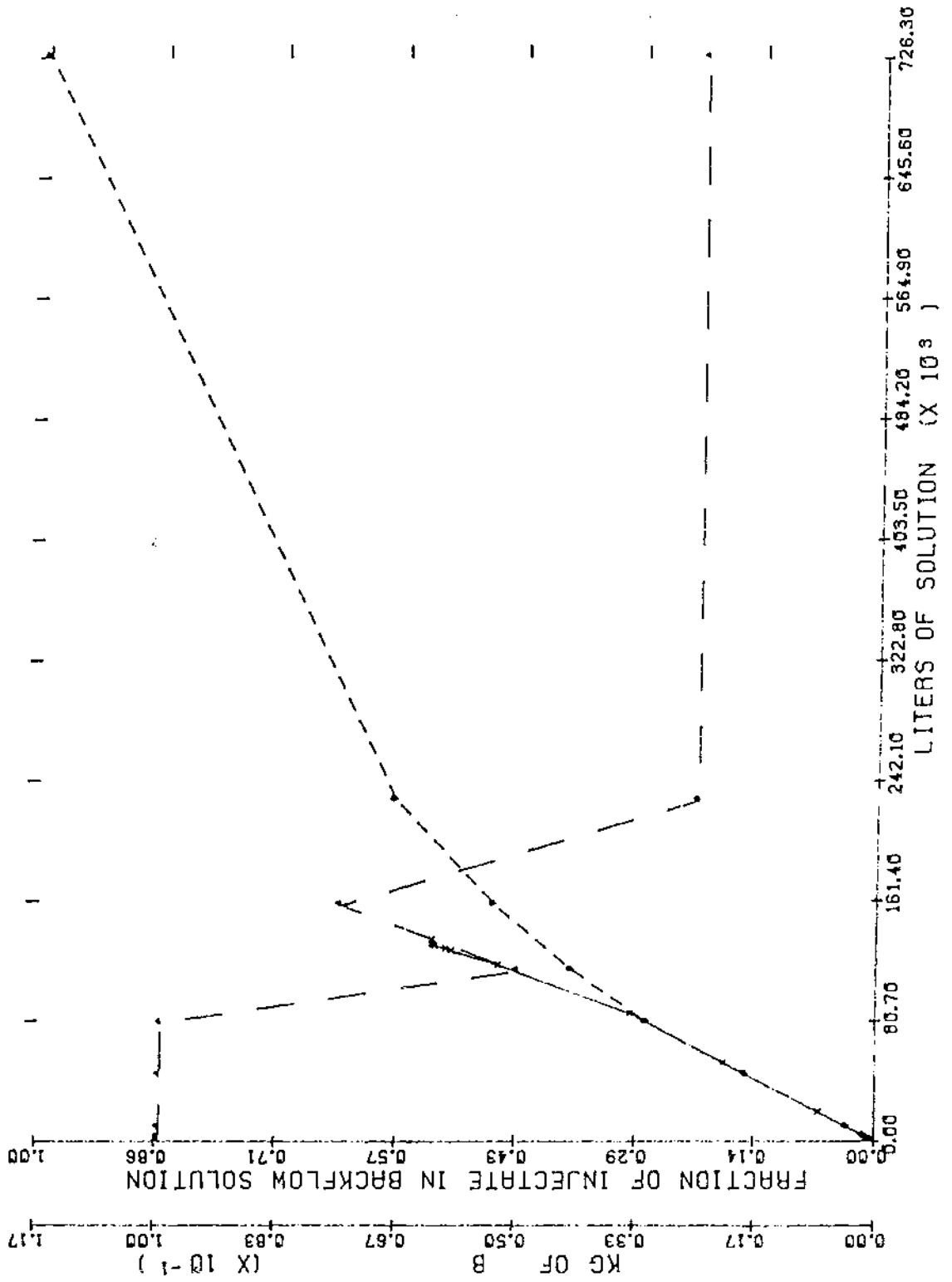
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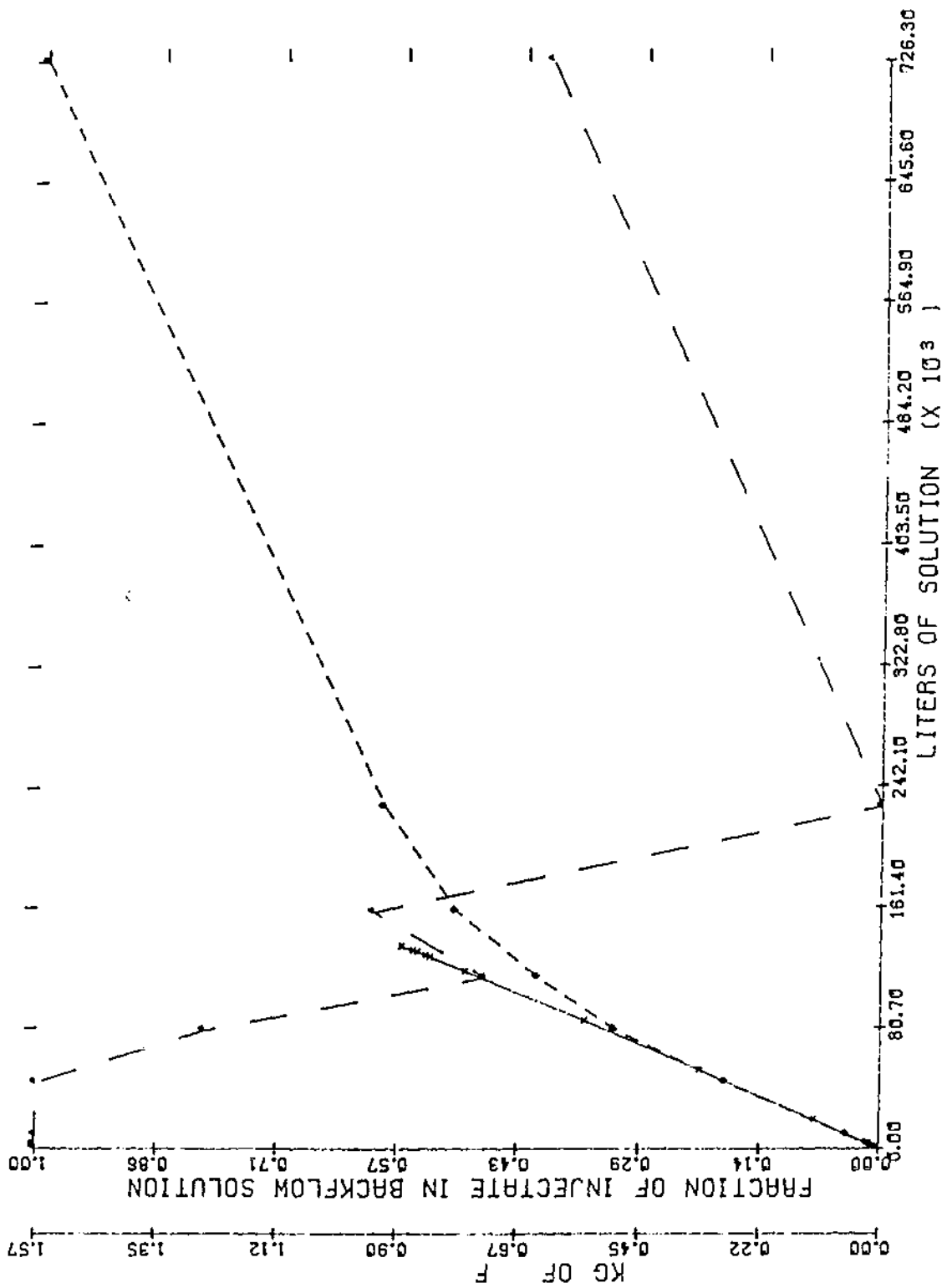
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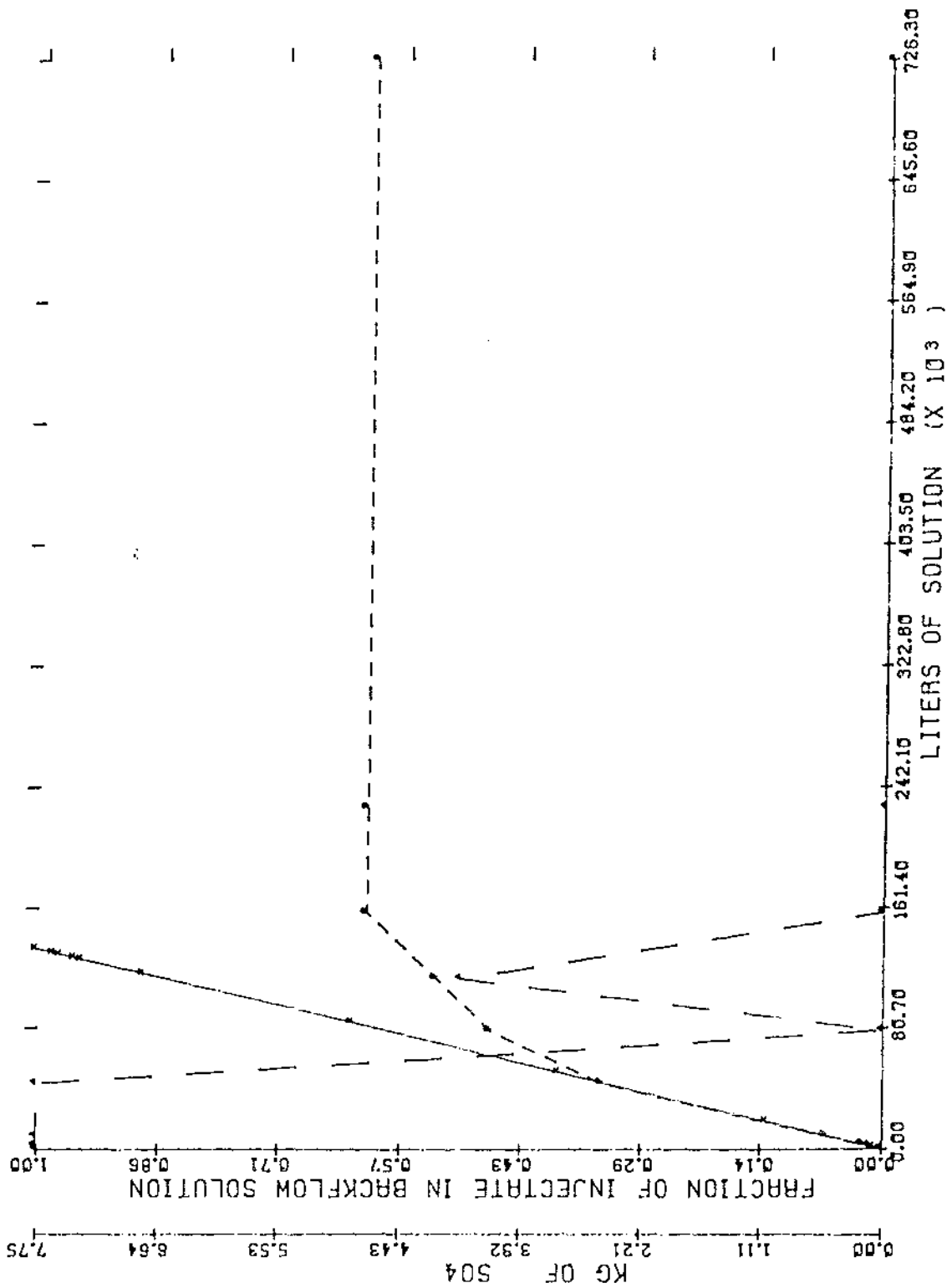
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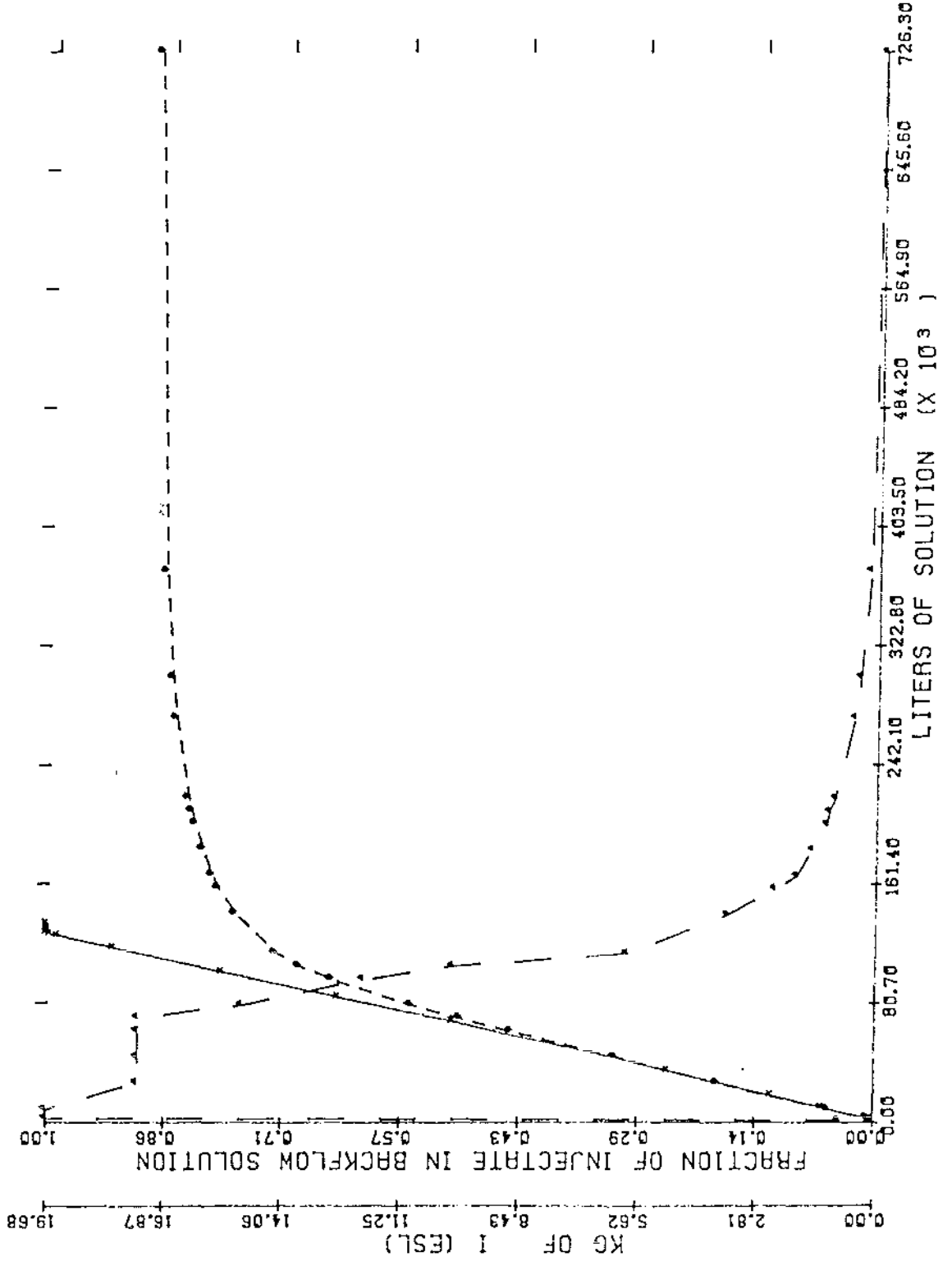
TEST 2A-2, RAFT RIVER



TEST 2A-2, RAFT RIVER



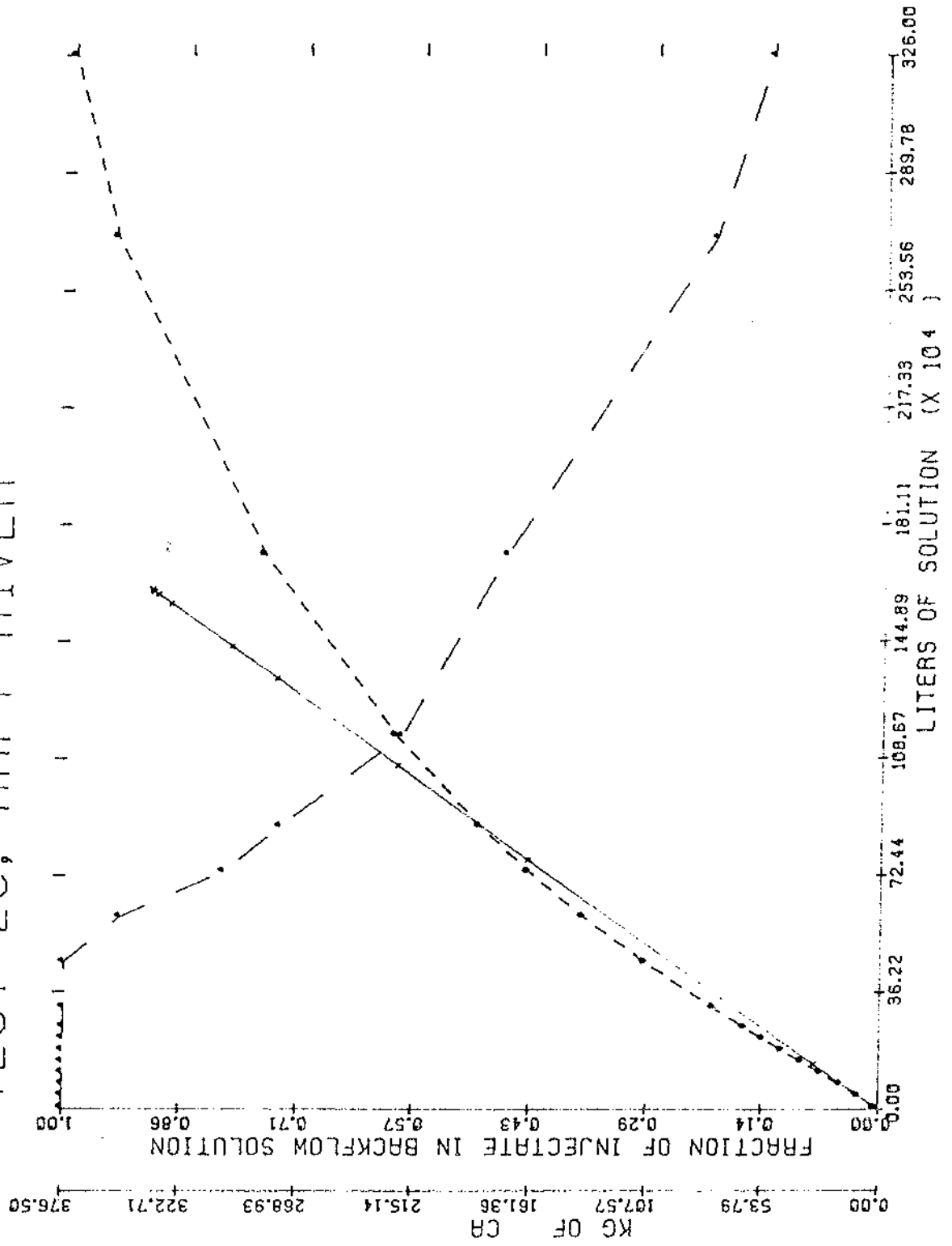
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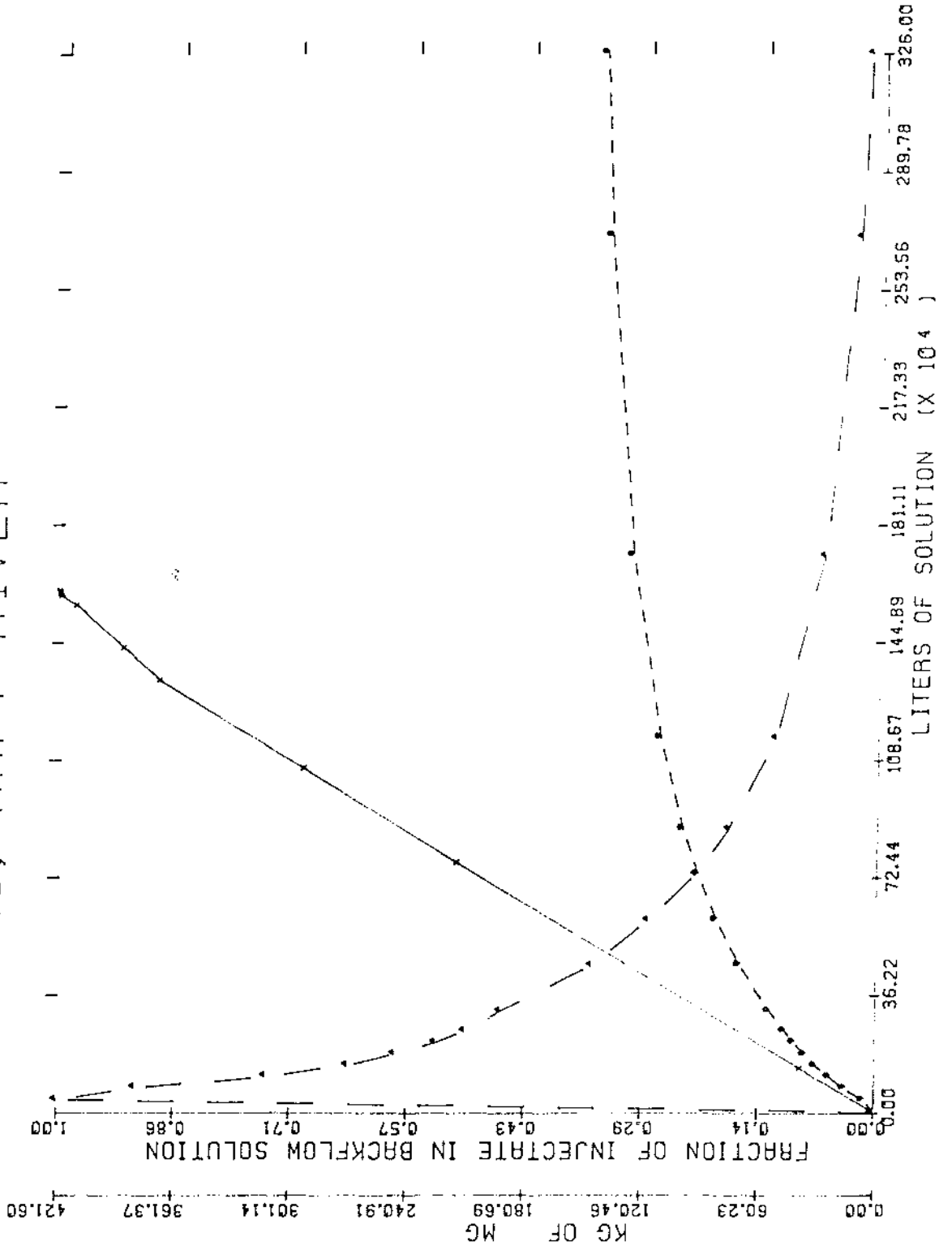
APPENDIX B2-2
Recovery Curves Test 2C

For the recovery curves in this Appendix a long dashed line connecting triangles represents the fraction of injectate in the backflow solution, the solid line connecting x's represents the Kg's of the element injected and the short dashed line connecting hexagons represents the Kg's of the element backflowed.

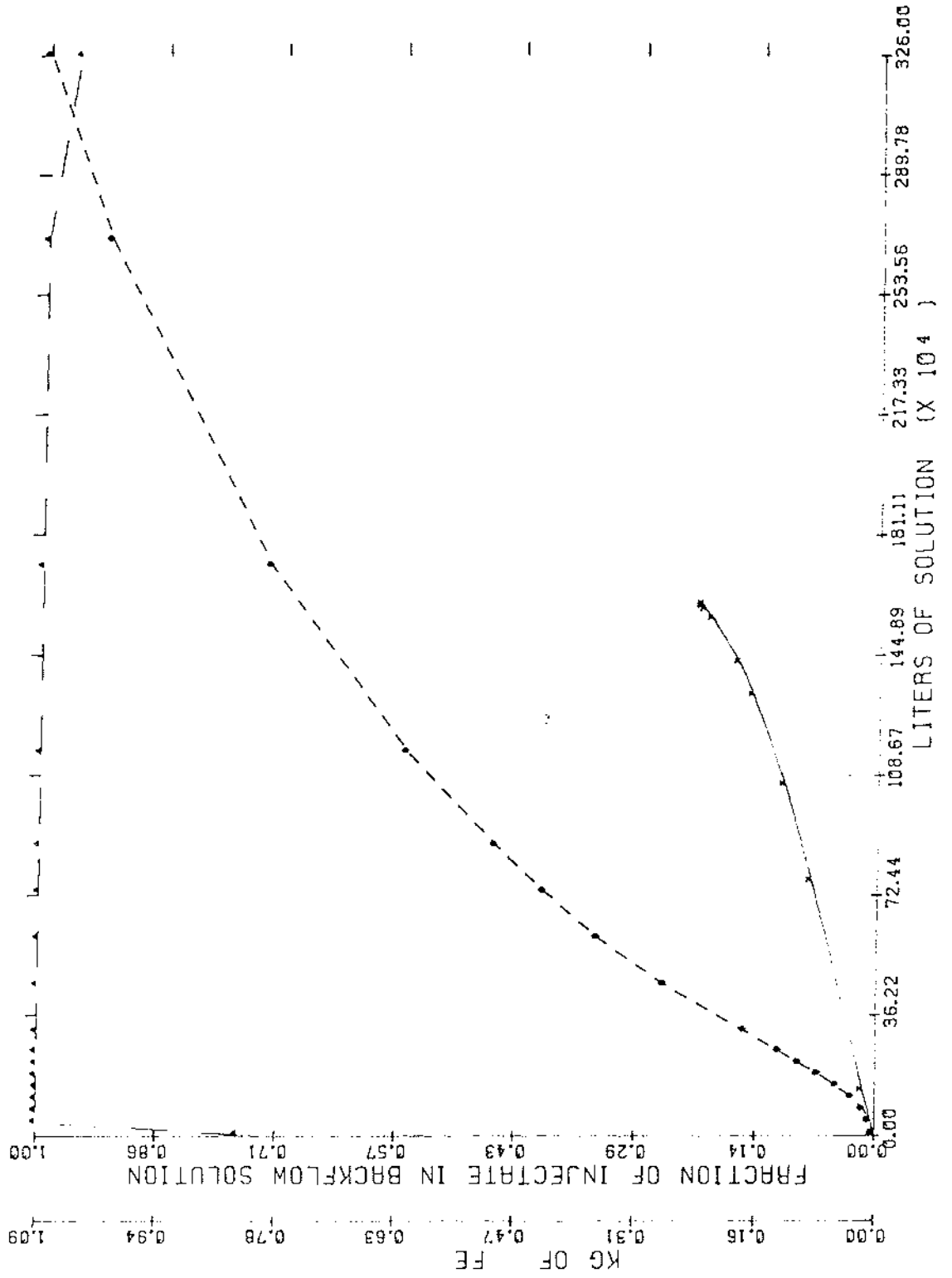
TEST 2C, RAFT RIVER



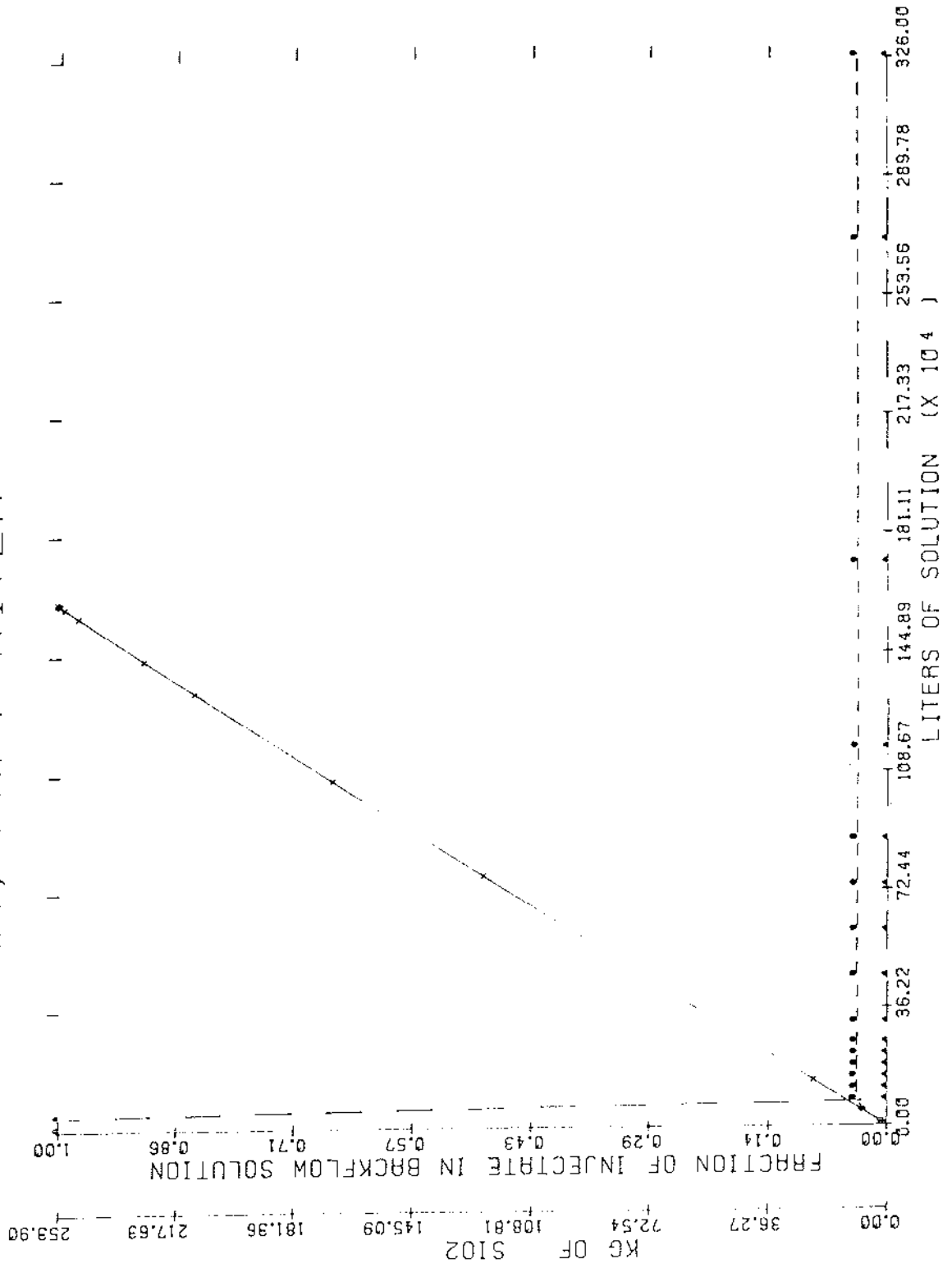
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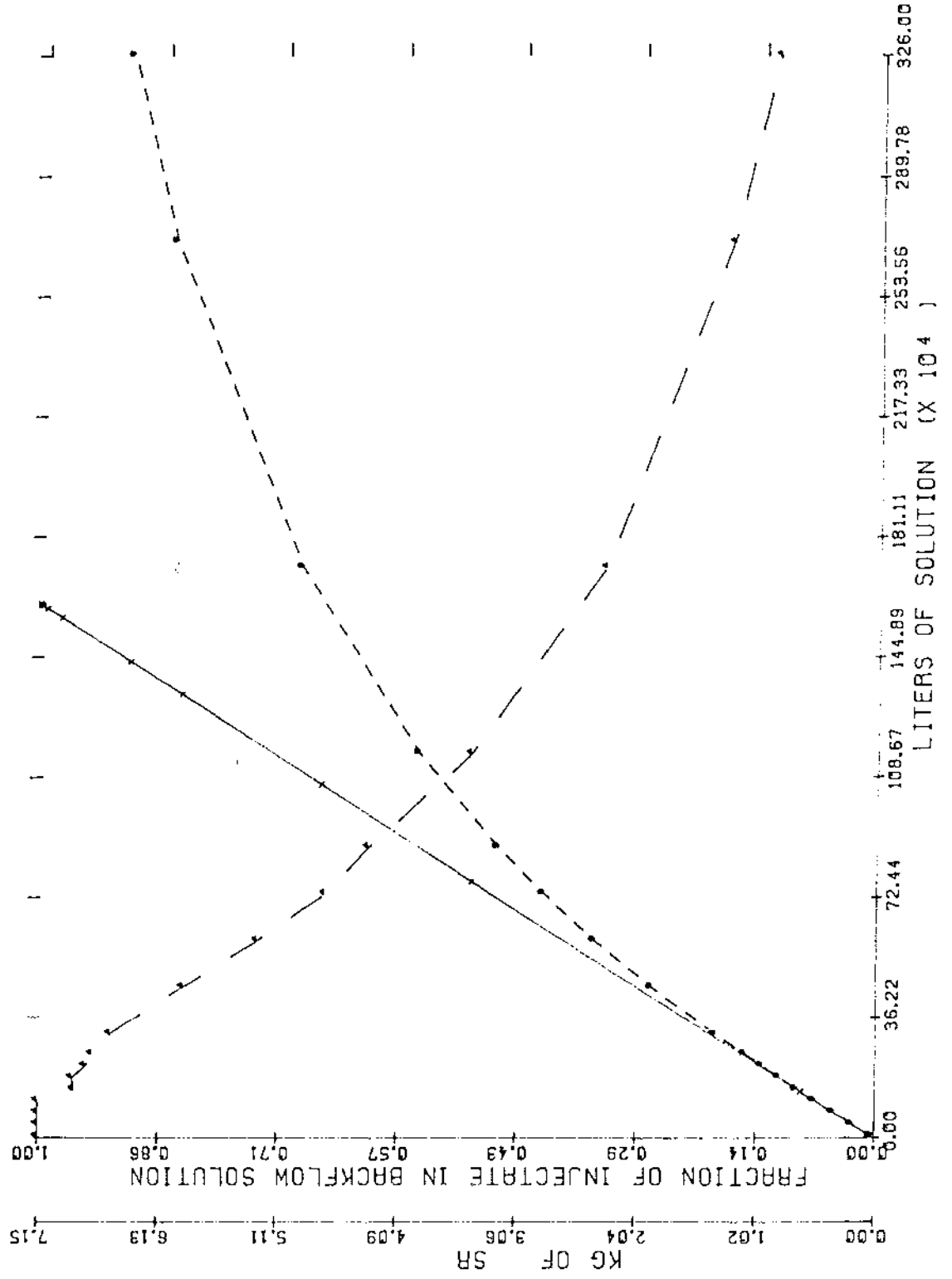
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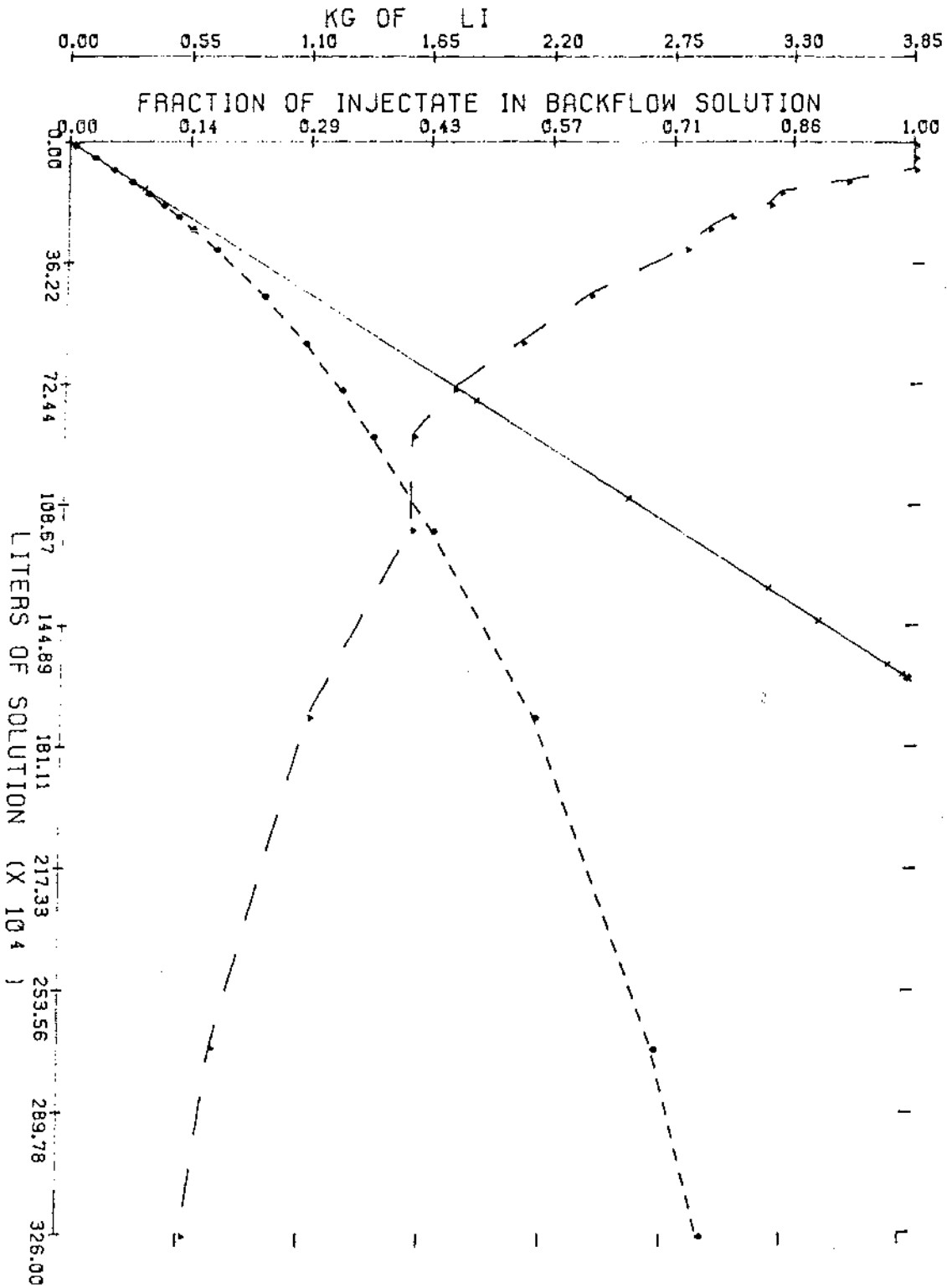
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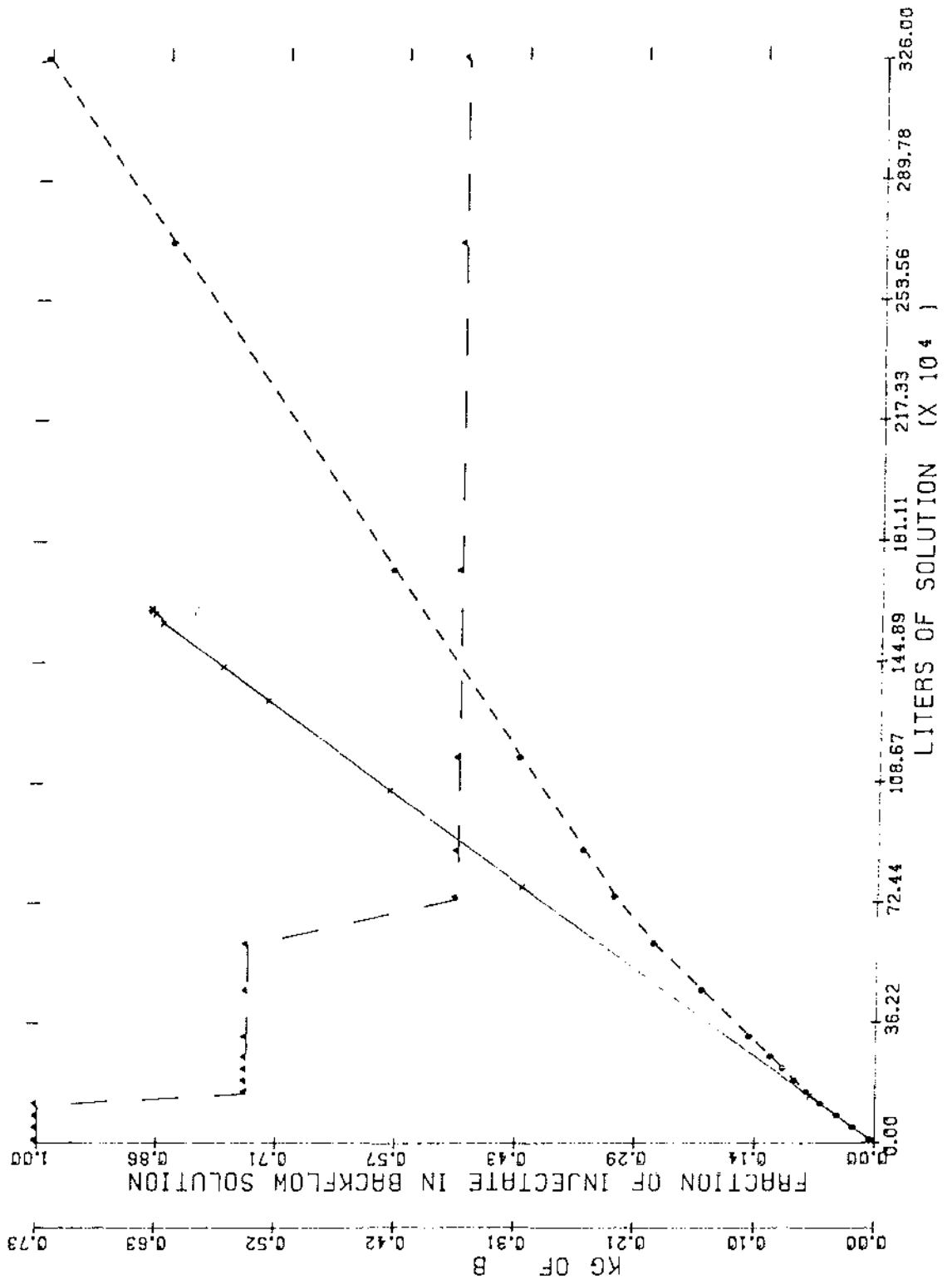
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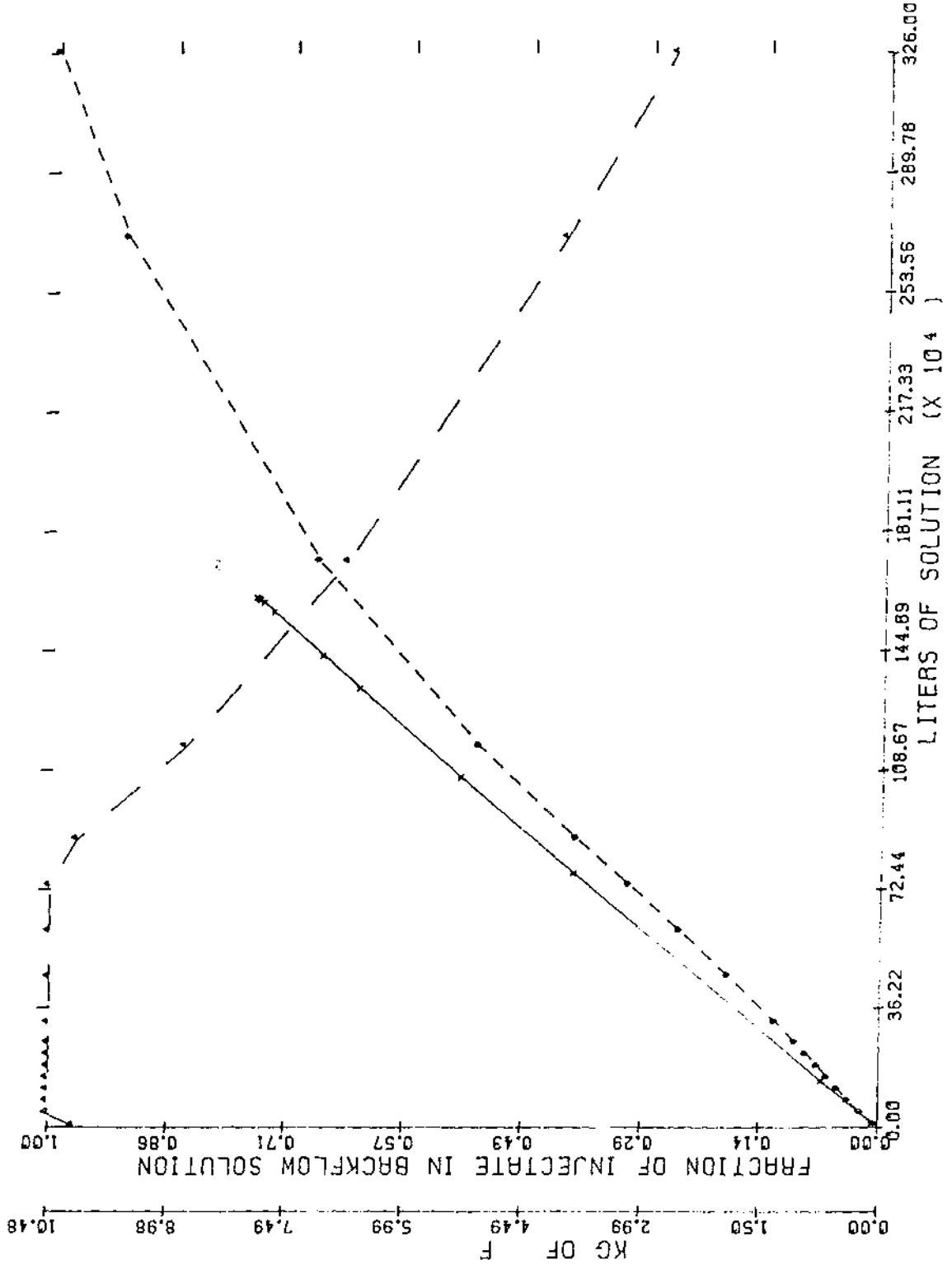
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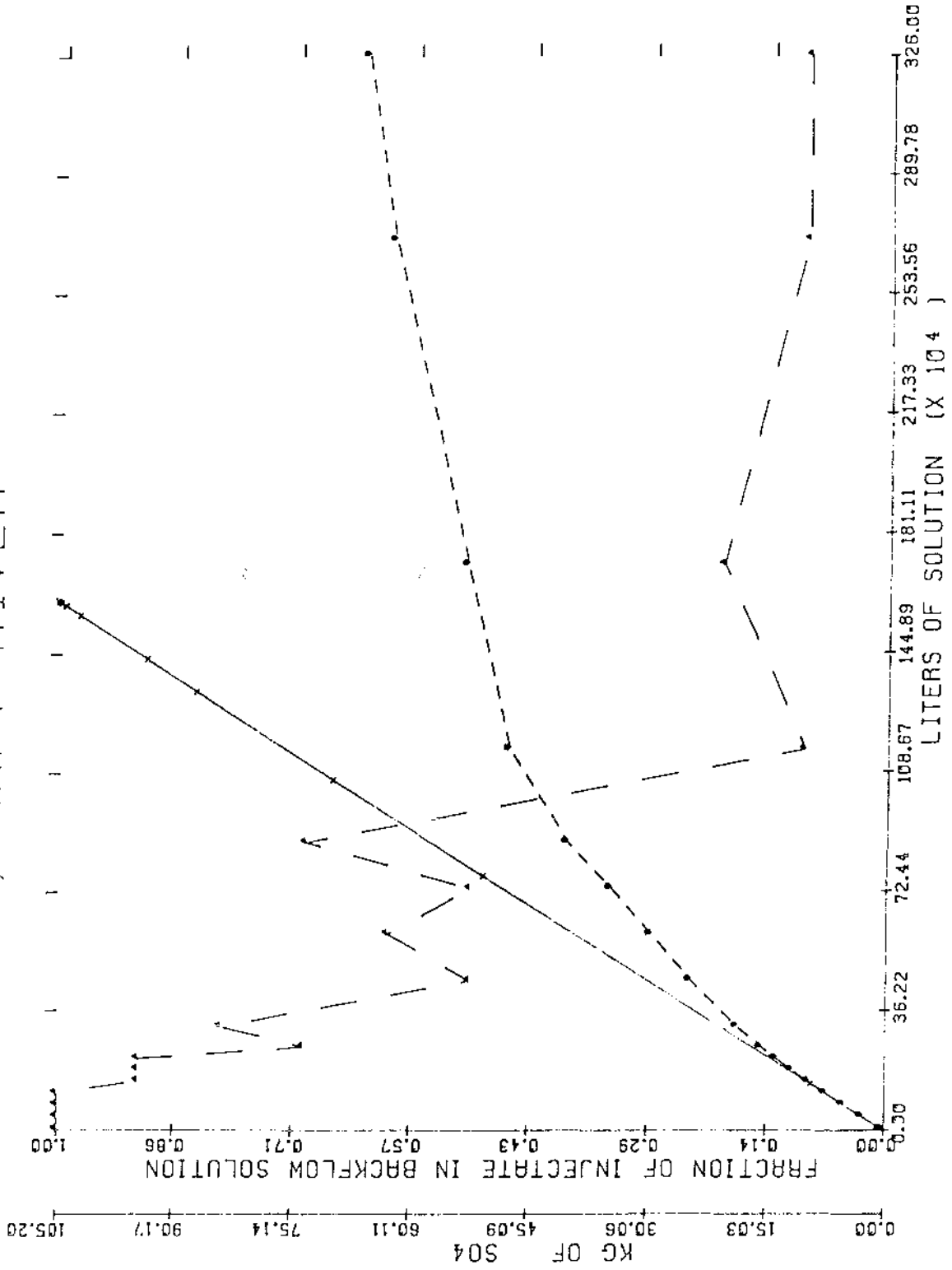
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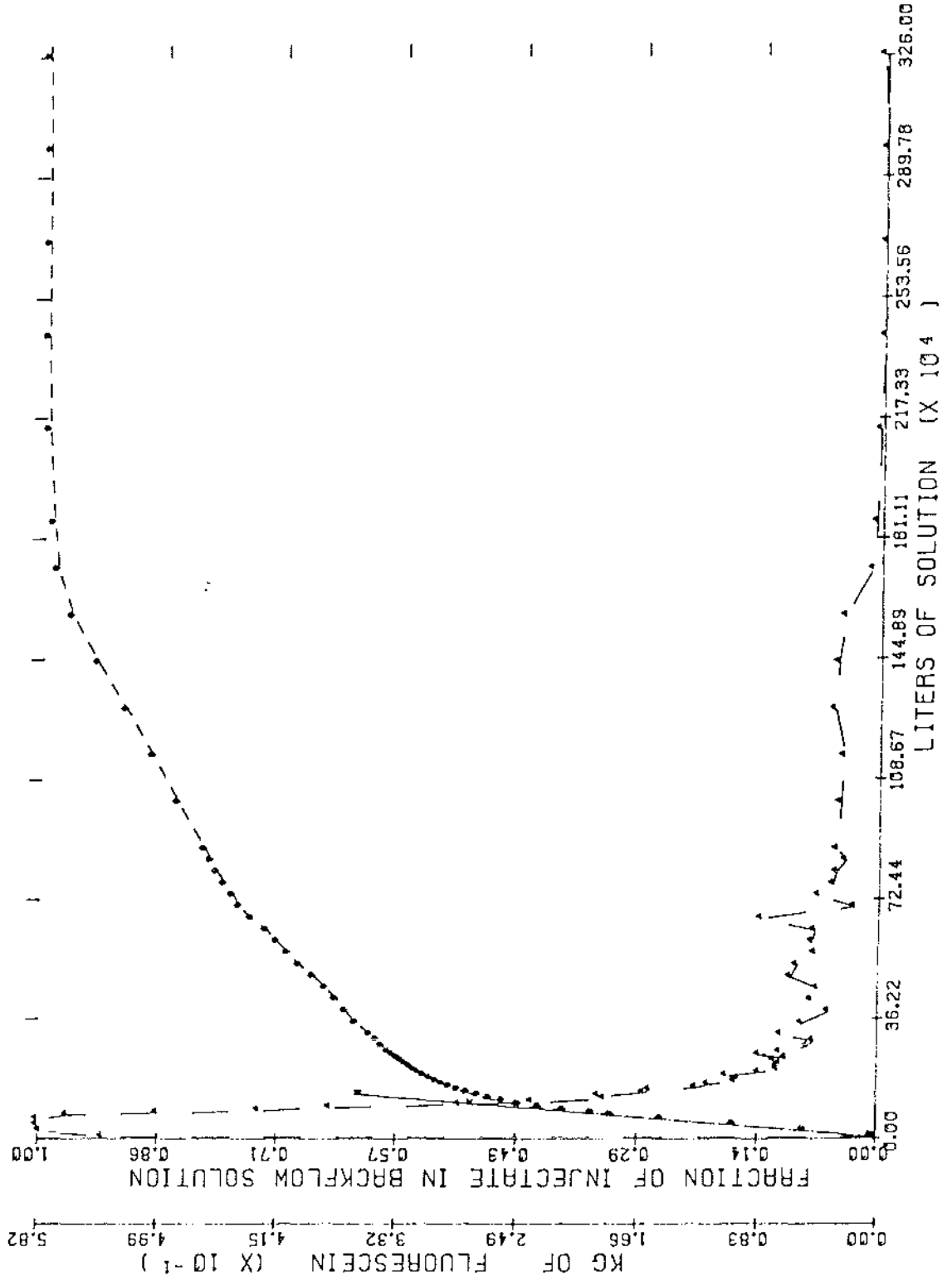
TEST 2C, RAFT RIVER



TEST 2C, RAFT RIVER



TEST 2C, RAFT RIVER

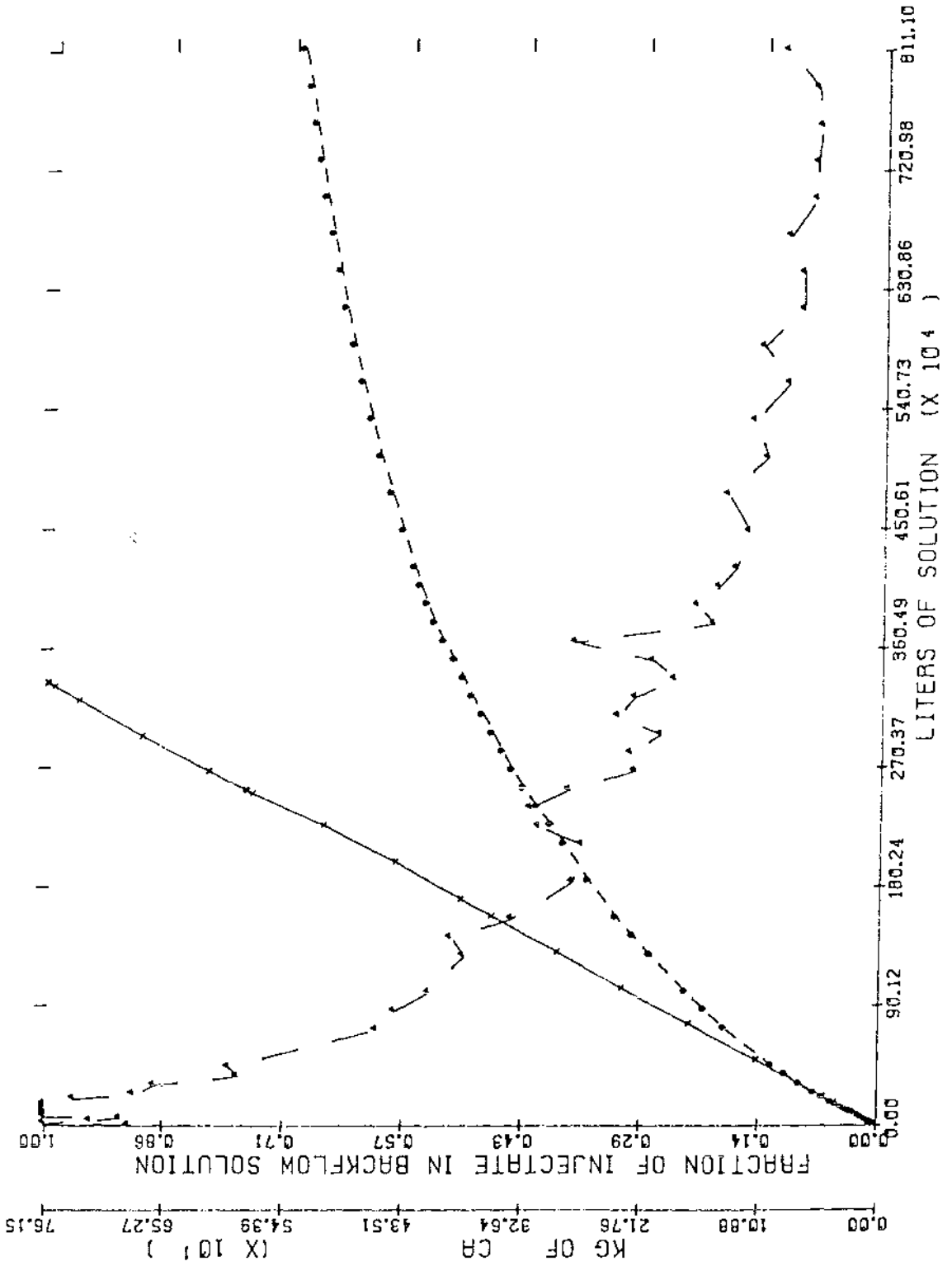


APPENDIX B2-3

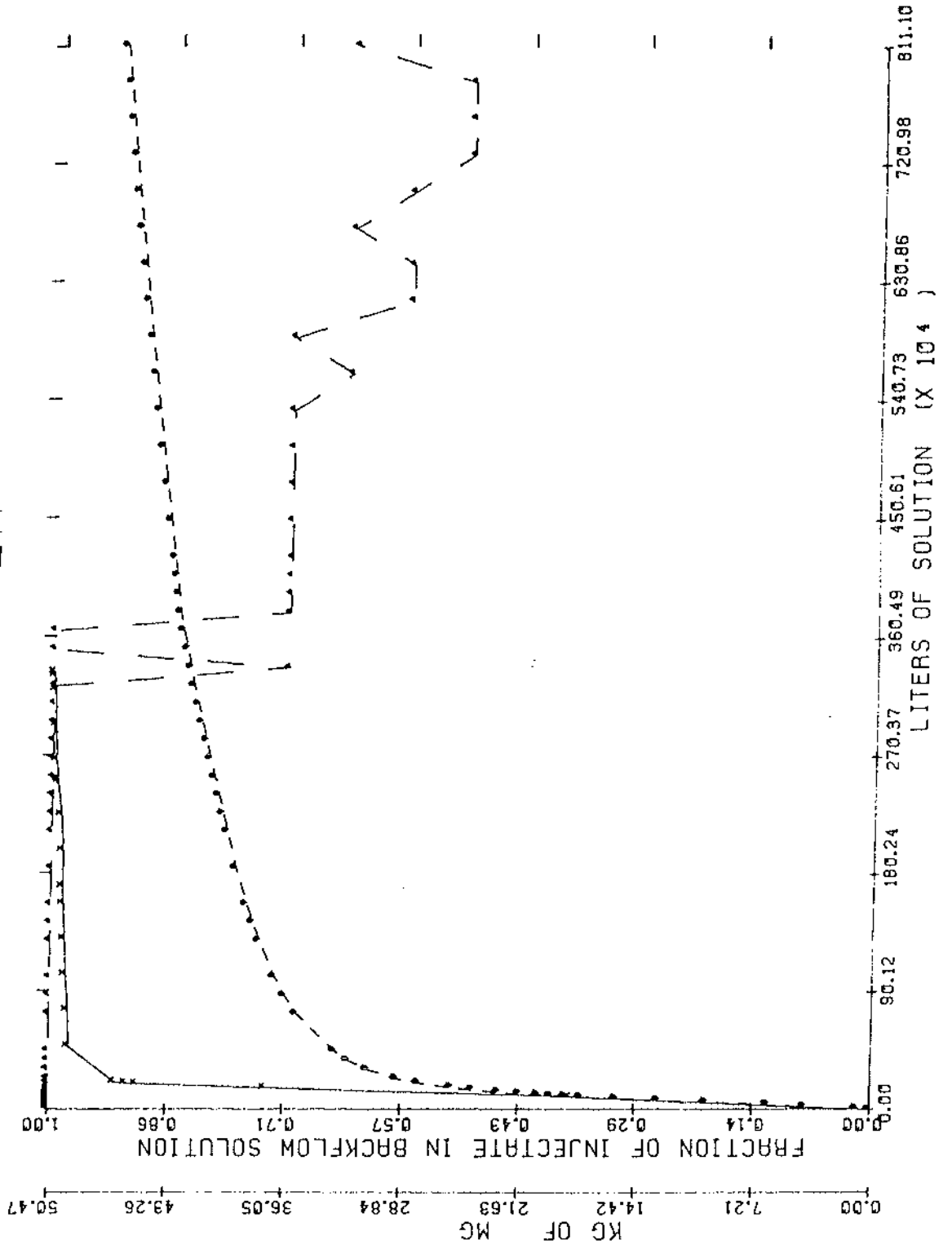
Recovery Curves Test 2D

For the recovery curves in this Appendix a long dashed line connecting triangles represents the fraction of injectate in the backflow solution, the solid line connecting x's represents the K_g 's of the element injected and the short dashed line connecting hexagons represents the K_g 's of the element backflowed.

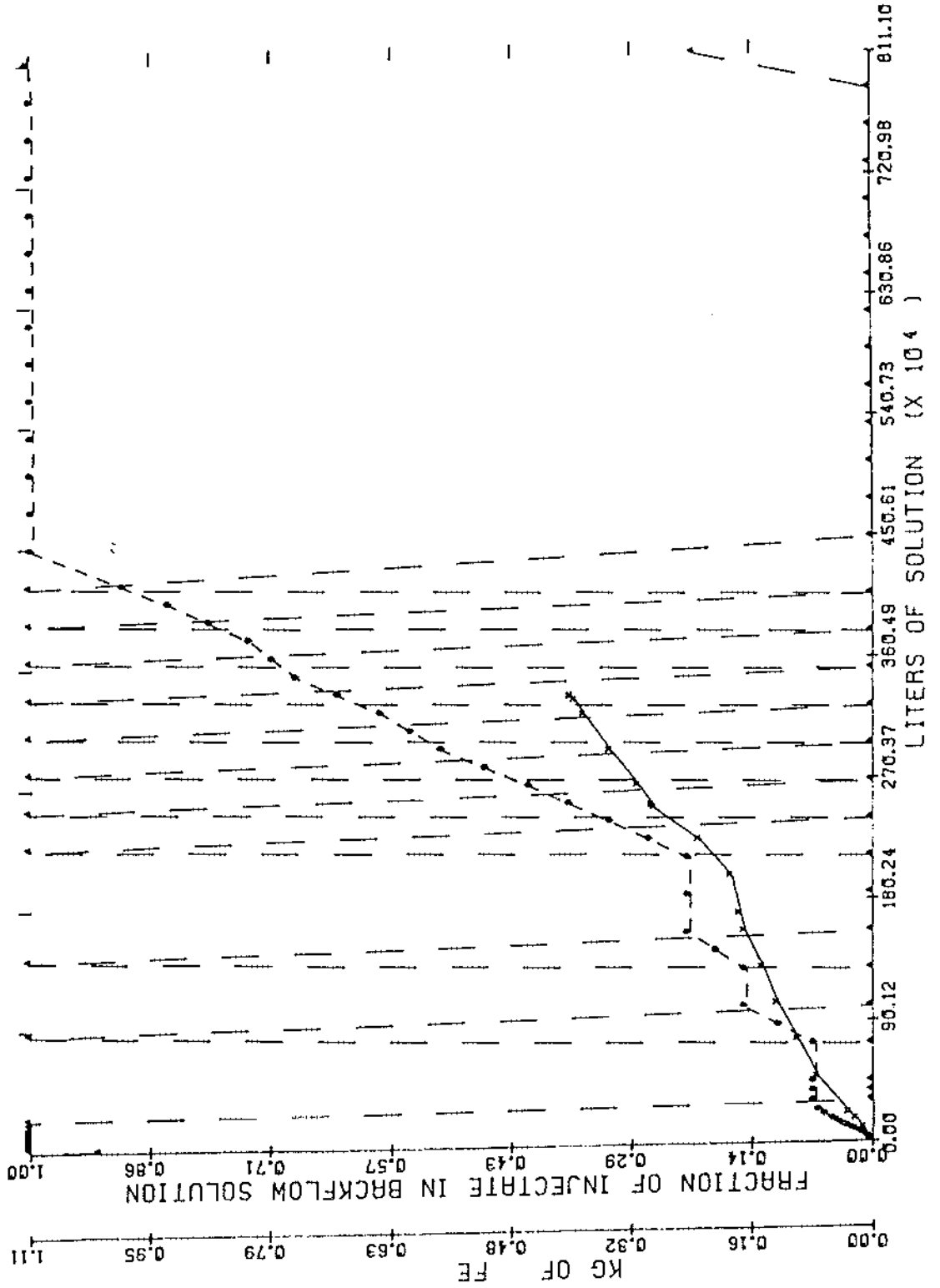
TEST 2D, RAFT RIVER



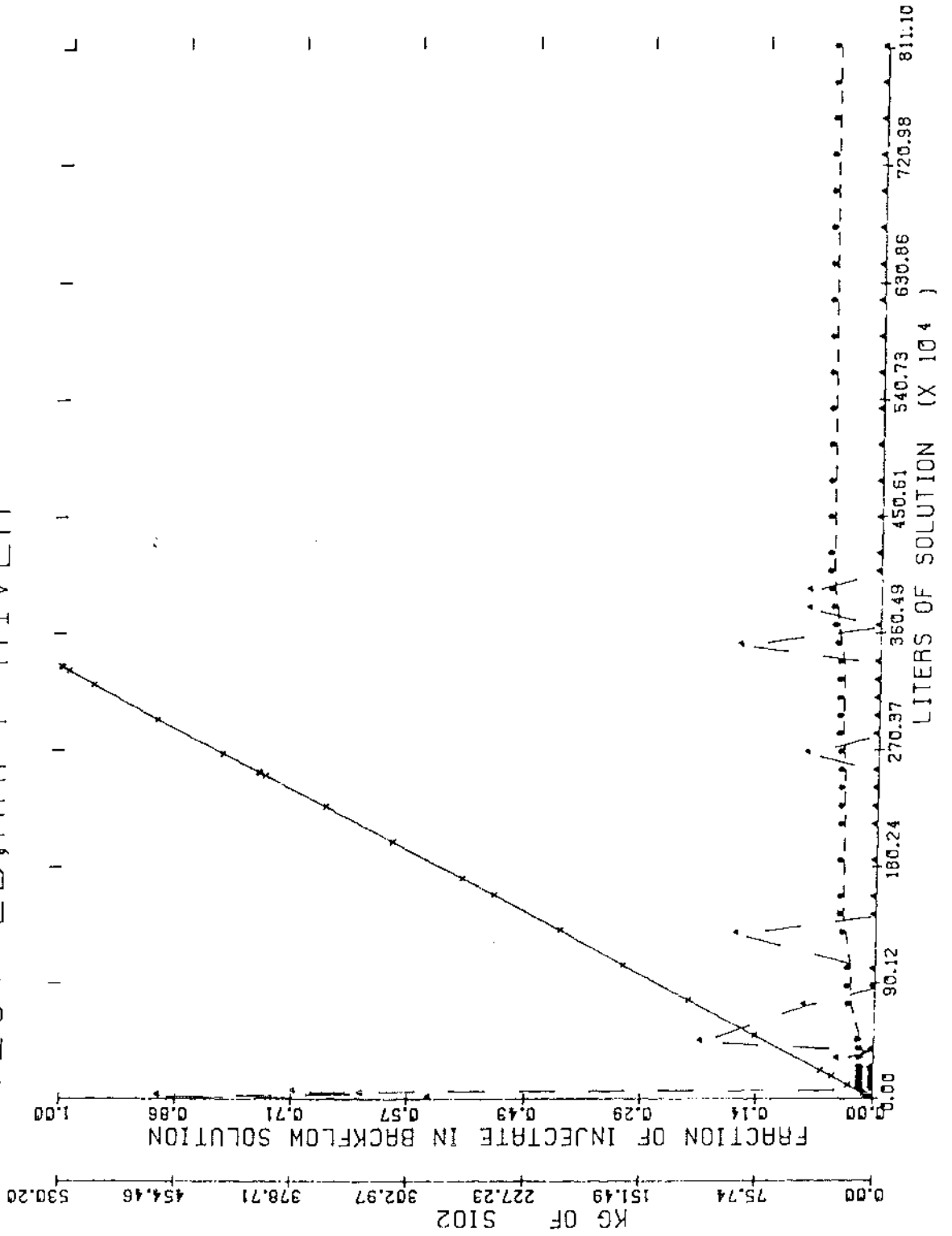
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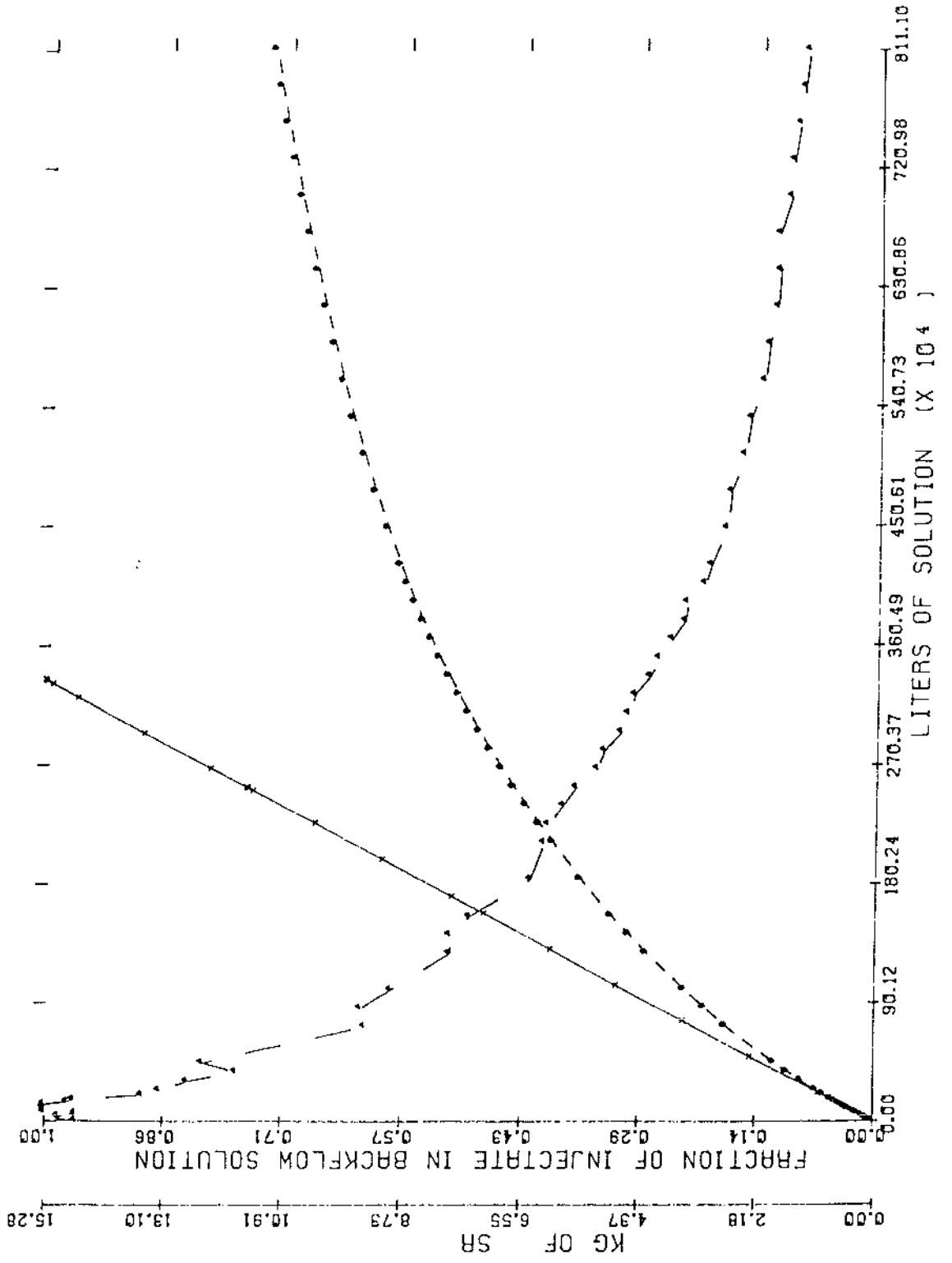
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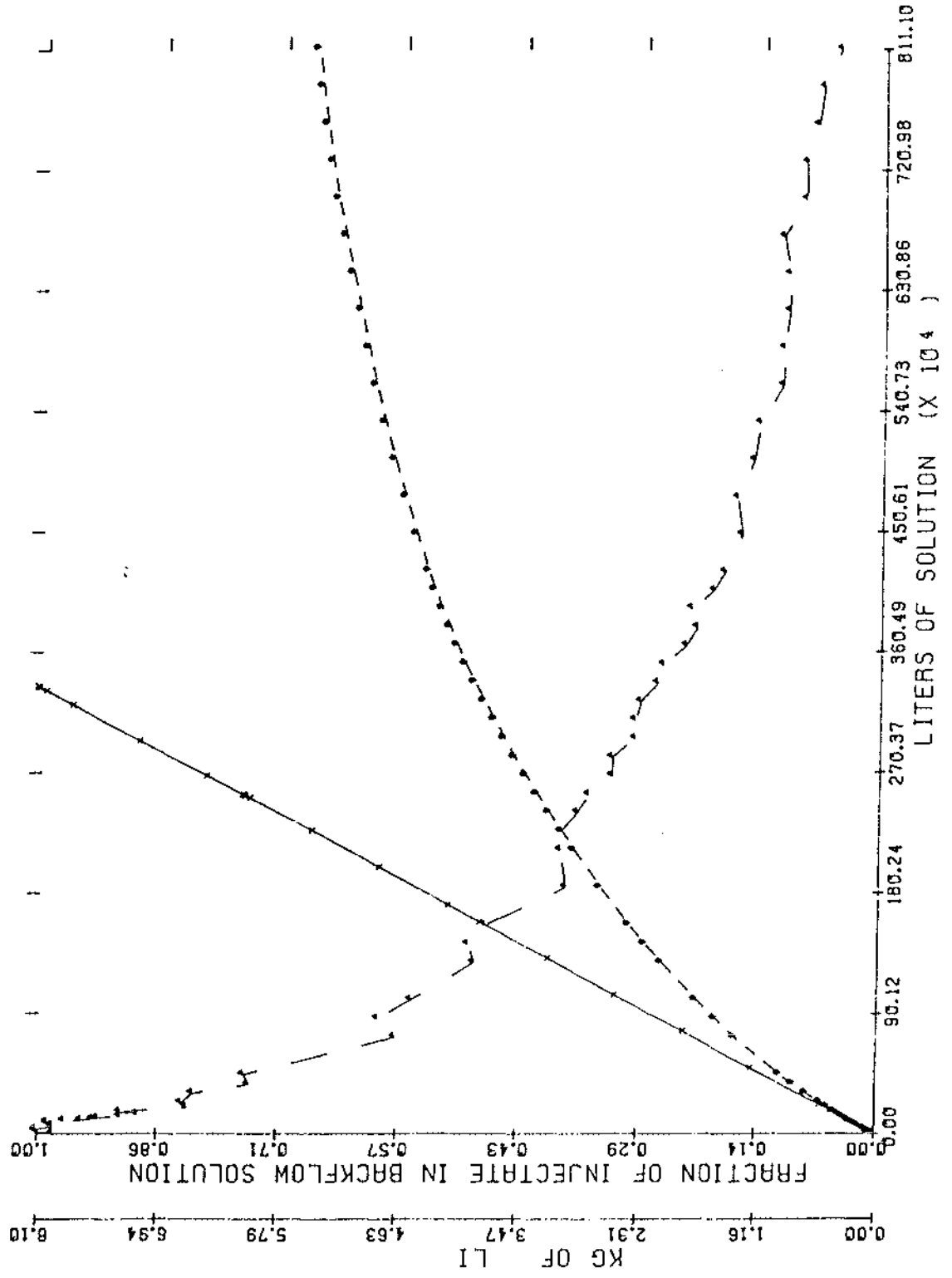
TEST 20, RAFT RIVER



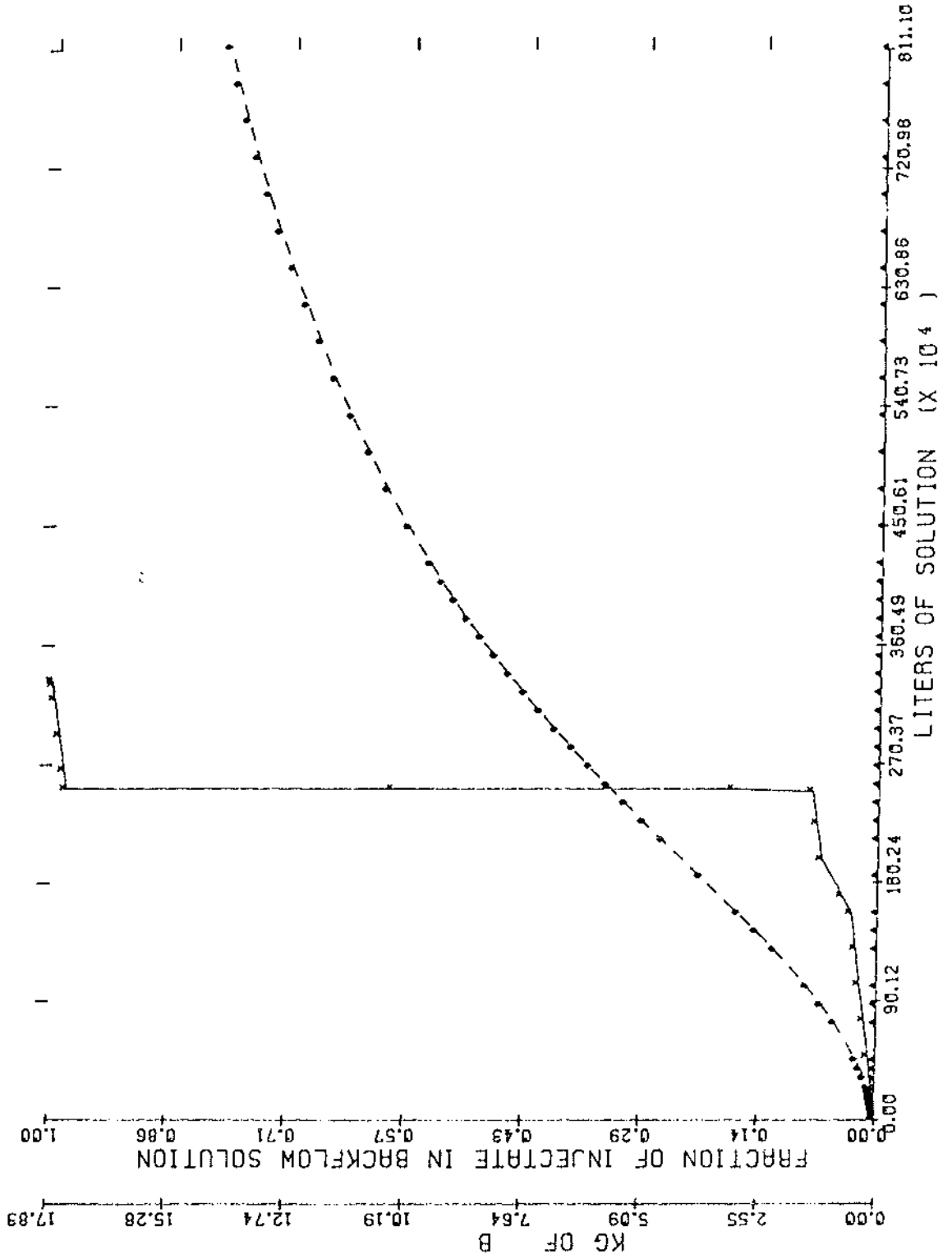
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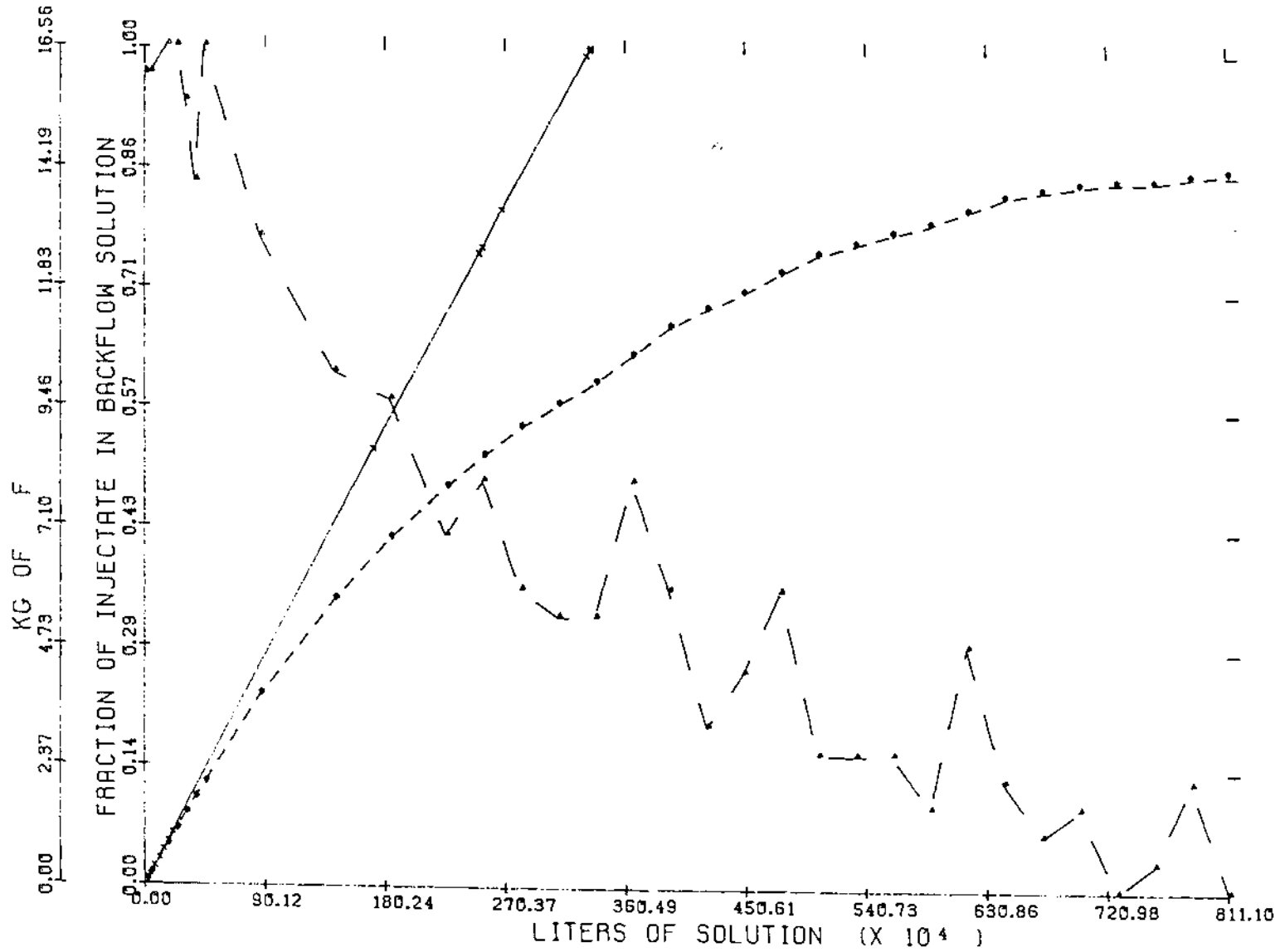
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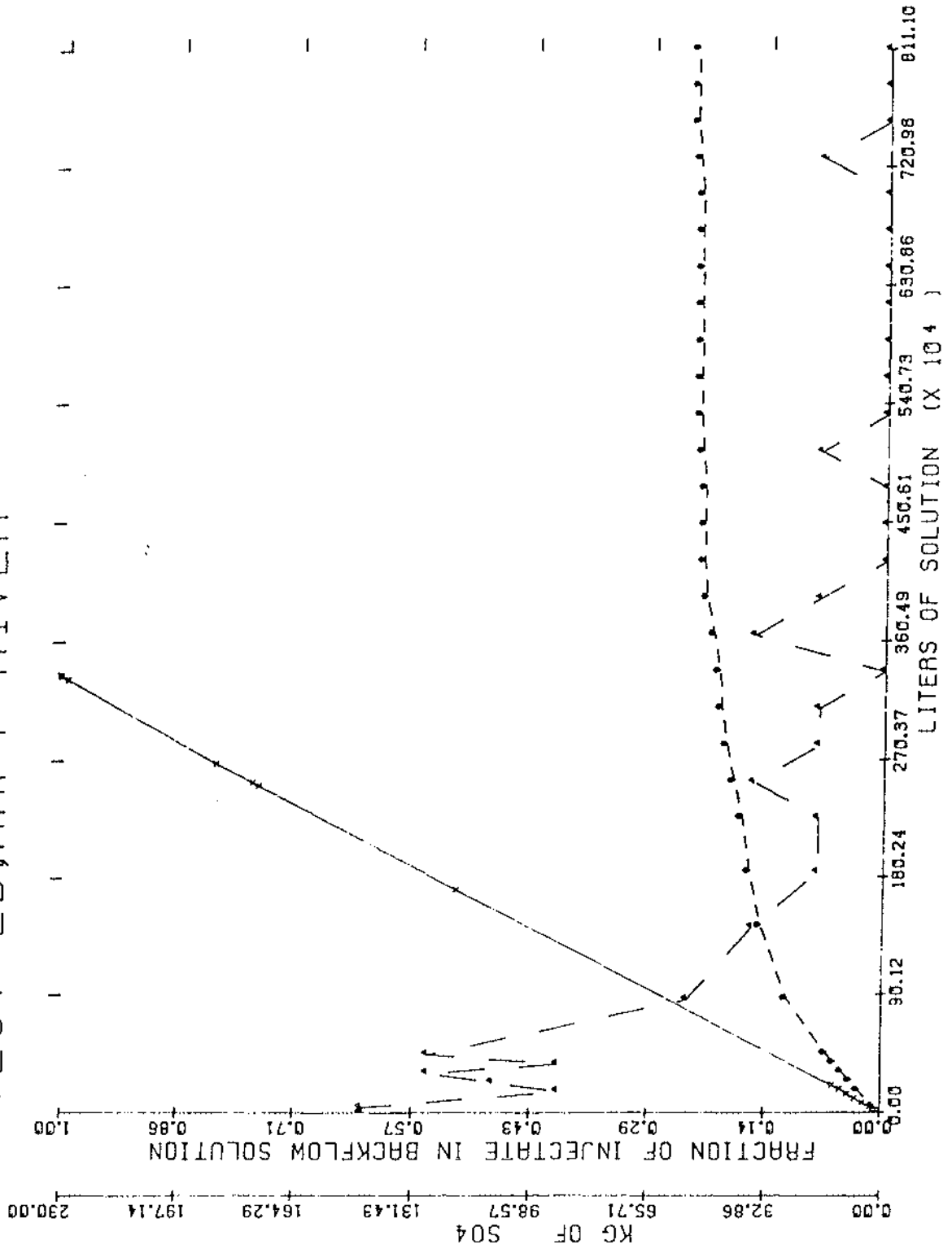
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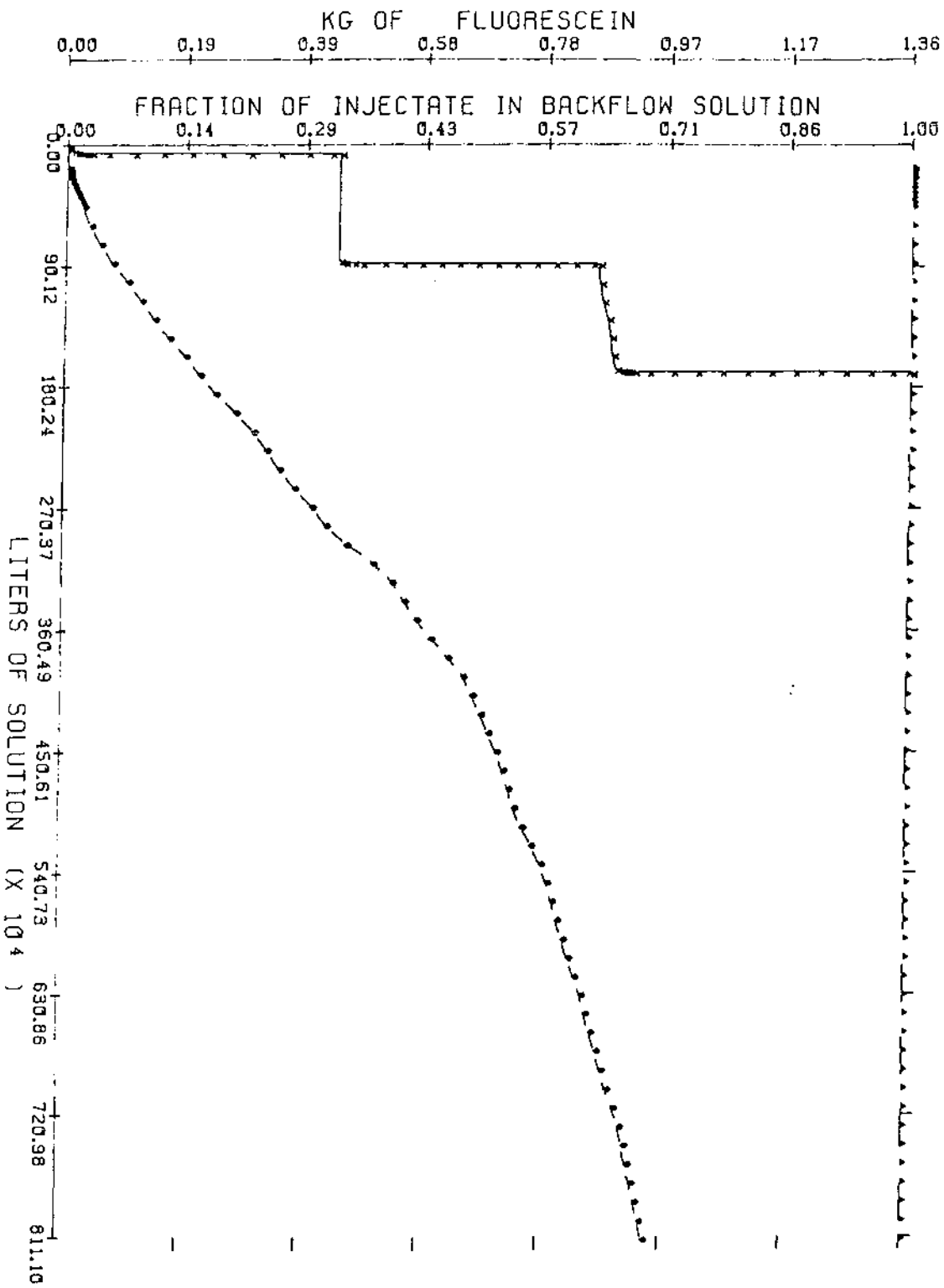
TEST 2D, RAFT RIVER



TEST 20, RAFT RIVER



TEST 2D, RAFT RIVER



TEST 20, RAFT RIVER

