NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

UNCERTAINTY IN THE CALIBRATION OF THE DH-48 SUSPENDED SEDIMENT SAMPLER

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NWRI CONTRIBUTION 92-18

MANAGEMENT PERSPECTIVE

Suspended sediment concentrations are an important indicator of water quality in rivers. To ensure that reliable data are obtained, the Monitoring and Surveys Division (MSD) of the Surveys and Information Systems Branch (SISB) of Environment Canada, is in the process of developing a quality assurance program for the 500 samplers of various types currently in use by the Department. The National Water Research Institute (NWRI) is assisting SISB in the development of a calibration strategy for suspended sediment samplers used in the national program. Towing tank tests on the DH-48 suspended sediment sampler were conducted to determine the repeatability of their calibration and their need for calibration. It has been shown that only limited calibration of the DH-48 sampler is required to ensure that its performance is within acceptable limits. It was further shown that nozzles issued with a sampler can be exchanged with nozzles of the same type in the field without further need for calibrations. These findings will result in reduced operating costs and increased efficiency in execution of measurement programs. Similar tests on other types of samplers are proceeding.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les concentrations de sédiments en suspension sont un important indicateur de la qualité de l'eau des rivières. Pour assurer la fiabilité des données, la Division de la surveillance et des relevés de la Direction des relevés et des systèmes d'information d'Environnement Canada, est en voie de mettre au point un programme d'assurance de la qualité pour les 500 échantillonneurs de différents types couramment utilisées par le Ministère. L'Institut nationale de recherche sur les eaux (INRE) collabore avec la Direction des relevés et des systèmes d'information à la formulation d'une stratégie d'étalonnage des échantillonneurs de sédiments en suspension utilisés dans le cadre du programme national. Des essais dans le canal à chariot mobile de l'échantillonneur à sédiments en suspension DH-48 ont été menés afin d'établir la répétabilité de l'étalonnage et sa nécessité. Il a été montré que seul un étalonnage limité de l'échantillonneur DH-48 est nécessaire, et que l'on peut échanger des buses sur place sans qu'il soit nécessaire d'effectuer un autre étalonnage. Ces résultats se traduiront par une réduction des frais d'exploitation et une efficacité accrue au niveau de l'exécution des programmes de mesure. Des essais similaires sur d'autres types d'échantillonneurs sont en cours.

ABSTRACT

Tests were conducted in the towing tank at NWRI on a DH-48 sediment sampler with carefully selected nozzles. Statistical analysis of the test data were conducted. It was shown that this type of sampler can be calibrated with a sufficient degree of repeatability and that complete calibration of individual samplers is not necessary. It was further shown that nozzles issued with each sampler can be exchanged with similar nozzles in the field and no further calibrations are required.

RÉSUMÉ

Des essais dans le canal à chariot mobile ont été effectués sur un échantillonneur de sédiments DH-48 au moyen de buses bien précises. L'analyse statistique des données d'essais a été effectuée. Il a été montré que ce type d'échantillonneur peut être étalonné avec un degré de répétabilité suffisant et qu'il n'est pas nécessaire d'étalonner chaque échantillonneur. On a montré en outre qu'il est possible d'échanger sur place les buses recommandées pour cet échantillonneur et qu'il n'est pas nécessaire d'effectuer d'autres étalonnages.

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1. INTRODUCTION

Data of suspended sediment concentration in rivers have become increasingly important because the fine fractions of the sediment load are known to be carriers of toxic substances. As a result, suspended sediment concentrations are an important indicator of water quality in rivers. The accuracy of all suspended sediment samplers must be checked to ensure that reliable data are obtained throughout the data collection program conducted by the federal Department of the Environment. At the present time, the Monitoring and Surveys Division (MSD) of the Surveys and Information Systems Branch (SISB), with the assistance of the National Water Research Institute (NWRI), is in the process of developing a calibration strategy for all suspended sediment samplers used in the national data gathering program. This report presents the results of tests conducted on the DH-48 sampler in the towing tank of the NWRI Hydraulics Laboratory at Burlington, Ontario.

2. PRELIMINARY CONSIDERATIONS

The purpose of the suspended sediment sampler is to obtain a sample that is representative of the water-sediment mixture moving in the vicinity of the sampler. During the sampling, a volume of the water-sediment mixture is collected in the sampler over a measured interval of time, using predetermined transit rates (Guy and Norman 1970, Beverage 1979). From the measured volume and the transit time, the flow rate into the sampler is determined. The velocity of the flow through the nozzle is computed by dividing the flow rate by the cross-sectional area of the nozzle flow passage entrance. The sediment flux is the product of the sediment concentration of the collected sample and the nozzle velocity.

Suspended sediment samplers are operated on the premise that the velocity of flow through the nozzle is equal to the velocity of the stream flow surrounding the nozzle (Beverage 1970). This condition is known as iso-kinetic sampling. For sediment sampling quality control, the nozzle velocity V_n and the stream flow velocity V_s are expressed as a ratio given by

$$K = \frac{V_n}{V_s} \tag{1}$$

where K is the sampler performance coefficient. For iso-kinetic conditions, $K = 1$ and it is assumed that the flow entering through the nozzle contains the same sediment-water mixture as the stream flow being sampled. When the suspended sediment is sand and $K > 1$, the sampler will under-sample the suspended sediment concentration, whereas when $K < 1$, the sampler will over-sample (Beverage 1979, Beverage and Futrell 1986). For a given flow velocity, errors in sample concentration become increasingly sensitive to the value of K as the particle size increases. For silts and clays, the sample concentration is less sensitive to K because the particle are more evenly dispersed thorough in the flow.

The performance of the DH-48 sampler can be evaluated by examining the variation of K with towing velocity. The accuracy of a given sampler calibration is reflected by the uncertainty in the value of K at different towing velocities over its operating range. The sampler to sampler variability can be determined by comparing values of K for different DH-48 samplers for the same towing velocity. Finally, the effect of using different nozzles of a given size and type, can be determined by examining the change in the sampler performance coefficient.

3. EXPERIMENTAL EQUIPMENT AND PROCEDURE

3.1 Towing Tank

The towing tank used to test the sampler is 122 m long by 5 m wide and is constructed of reinforced concrete founded on piles. The full depth of the tank is 3 metres, of which 1.5 metres are below ground level. Normally the water depth is maintained at 2.7 metres. Concrete was chosen for its stability and to reduce possible vibrations and convection currents.

At one end of the tank is an overflow weir. Waves arising from towed objects and their suspensions are washed over the crest, thereby reducing wave reflections. Parallel to the sides of the tank perforated beaches serve to dampen lateral surface wave disturbances.

3.2 Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tonnes and travels on four precision machined steel wheels. The carriage is operated in three overlapping speed ranges:

0.005 m/s - 0.06 m/s

0.05 m/s - 0.60 m/s

0.50 m/s - 6.00 m/s

The maximum speed of 6.00 m/s can be maintained for 12 seconds. Tachometer generators connected to the drive shafts emit a voltage signal proportional to the speed of the carriage. A feedback control system uses these signals as input to maintain constant speed during tests. The average speed data for the towing carriage is obtained by recording the voltage pulses emitted from a measuring wheel. This wheel is attached to the frame of the towing carriage and travels on one of the towing tank rails, emitting a pulse for each millimeter of travel. The pulses and measured time are collected and processed to produce an average towing speed with a micro computer data acquisition system. Analysis of the towing speed variability by Engel (1989), showed that for speeds between 0.2 m/s and 3.00 m/s, the error in the mean speed was less than 0.15 percent at the 99 percent confidence level. Occasionally, these tolerances are exceeded as a result of irregular occurrences such as "spikes" in the data transmission system of the towing carriage. Tests with such anomalies are recognized by the computer and are automatically abandoned.

3.3 The DH-48 Sampler

The sampler consists of a cast aluminum housing, a pint "milk bottle", a wading rod and a teflon nozzle. The nozzle has an inside diameter of 6.4 mm (1/4") and geometric properties most suitable to the particular range of velocities shown in Table 1. The sampler and its appurtenances is shown in Figure 1.

The US DH-48 sampler is designed to sample low to medium velocity rivers by wading (Cashman 1988). When the sampler is lowered into the flow, air is expelled through a 3.0 mm diameter air vent at the side of the sampler cap. A small "horn" protruding from the sampler cap, just ahead of the air vent, presents a "bluff" body to the flow resulting in a small negative pressure pocket immediately behind it. This creates a "suction" effect which effectively reduces the energy drop through the air vent. Finally, the air vent outlet is located about 5 mm above the entrance of the nozzle flow passage. This creates a small positive, net hydro-static pressure which is constant regardless of the depth of the sampler.

3.4 Selection of Test Nozzles

The nozzles were selected from samples tested by Engel (1991) in which twenty-five nozzles were selected for testing and marked as numbers S48-1 through S48-25. The tests were conducted in a new static test chamber, developed to determine the variability in the coefficient of velocity for suspended sediment sampler nozzles. Prior to testing, a nozzle was selected and fastened to the nozzle mount which was then secured in the base of the test chamber. The measurements consisted of the water level elevation above the nozzle entrance in the test chamber stilling well, the volume of water passing through the nozzle and the time required to pass that volume of water. For each value of static head, the discharge was measured by intercepting the outflow jet from the nozzle with the graduated cylinder and measuring the time to collect the water. The data were used to compute the velocity coefficient for each nozzle from the relationship

$$C_v = \frac{V_n}{V_t} \tag{3}$$

where C_v = the nozzle velocity coefficient, V_n = the flow velocity through the nozzle and V_t = the theoretical velocity of flow through the nozzle. The uncertainty in the velocity coefficients obtained with this method is less than 0.3% at the 95% confidence level (Engel 1990). Tests were conducted for each of the 25 nozzles.

To determine the uncertainty in the sampler calibrations, the nozzle having a velocity coefficient closest to the mean value for the sample of 25 nozzles was selected. This nozzle was designated as the standard nozzle because it was deemed to have the most representative properties of the nozzles used with the DH-48 sampler. This nozzle, numbered S48-3, was used with each of the 5 samplers tested. To determine the effect of changing nozzles on the sampler performance coefficient K, the nozzle, for which the difference between its value of C_v and the mean value for the sample was the greatest, was selected. This nozzle, numbered S48-23, was used with only one of the five samplers.

3.5 General Test Procedure

For a given nozzle the volume of water that can enter the sampler bottle in a given period of time should primarily depend on the physical properties of the nozzle and the air vent (Engel and Droppo 1990, Engel 1991 and Engel and Droppo 1992). In order to determine the uncertainty in the sampler performance coefficient, a series of experiments, each consisting of 10 tests over the range of velocities specified in Table 1, was conducted. At the beginning of each experiment, the nozzle was inserted into the sampler intake and the sampler assembled in its standard configuration as shown in Figure 1.

Once the sampler was prepared, the towing carriage was set into motion. When the carriage had reached its preset constant velocity, the sampler was submerged and held at 0.2 m below the surface of the water for the set period of time given in Table 1. The filling times in Table 1 are the maximum allowable without over-filling the bottle, thereby ensuring that there was no interference in the air flow through the vent. The tests were conducted in a towing tank because this afforded better control over the reference velocity than can be obtained in a flume. It has been shown that there is little difference between sampler calibrations obtained in a flume and in a towing tank (Beverage and Futrell 1986). Although, this procedure does not simulate actual stream sampling methods, it does, however, allow the operation of a sampler at a constant velocity. When the set period of sampling time had expired, the sampler was removed from the water and the volume of water determined with a 1000 ml graduated cylinder. The velocity of flow through the sampler nozzle was then computed from the equation

$$V_n = \frac{1.273 V_w}{d^2 t_s} \tag{2}$$

where d = the diameter of the flow passage through the nozzle in mm, V_w = the volume of water collected in c.c., t_s = the time over which the sampler was submerged in seconds. Each test was repeated 10 times to obtain a sufficiently large sample to determine the mean values and the uncertainties in the sampler performance coefficient K. Each test was begun at the lowest towing velocity given in Table 1 and continued at each subsequent velocity until the maximum was reached. The test data are given in Table 2.

4. DATA ANALYSIS

4.1 Performance Coefficient of DH-48 Sampler

Values of the performance coefficient K from Table 2 were plotted as K versus V_c for each of the five samplers as shown in Figure 2. In all cases the standard nozzle No. S48-3 was used. An average curve was fitted to the plotted data which can be interpreted to represent the mean performance of the DH-48 sampler. The curve shows that values of K are largest for the lowest velocities and that K decreases from a value of 1.3 when $V_c = 0.30$ m/s to 1.0 when $V_c = 1.0$ m/s. This shows that the DH-48 sampler is not truly iso-kinetic over its operating range. By definition, when $K > 1.0$, the velocity of the flow through the nozzle is greater than the ambient stream flow velocity (in this case the towing velocity V_c) As a result, the stream lines in the vicinity of the nozzle will converge sharply toward the nozzle intake. Sand particles, because of their inertia, will resist the sudden change in direction and the increase in water flow through the nozzle will not be accompanied by a corresponding increase in sediment particles. As a result, the sampler will under sample the sediment concentration (Engel and Droppo, 1990). This sampling deficit decreases as K decreases towards the ideal value of 1.0. In general, particle sizes in suspension are largely a function of flow velocity and level of turbulence, and therefore, a wide range of particle sizes can be obtained in a given sample. Therefore, when the sediment is sand or silt, it is desirable that samplers are capable of operating as close to iso-kinetic conditions as possible. When the sediment is composed of clay particles, the errors in sampling sediment concentration are less sensitive to the value of K because the particles are more evenly dispersed throughout the flow.

4.2 Uncertainty in the Value of K for a Particular Sampler

The true value of K, at a given velocity, for a particular sampler is the mean value of a very large sample, each determined experimentally under the same conditions. Such large samples are not feasible and values of K are inferred based on limited sample sizes. The true value of K is then said to lie between confidence limits defined by the relationship

$$\mu_K = \overline{K} \pm \frac{t_{0.975} S_K}{\sqrt{n-1}} \tag{3}$$

where μ_K = the mean value of K from a very large sample, $\overline{K}$ = the mean value of K from a limited sample, $t_{0.975}$ = the confidence coefficient at the 95% confidence level from Student's t distribution for $(n-1)$ degrees of freedom (Spiegel, 1961), S_K = the standard deviation of K about the sample mean $\overline{K}$ and n = the number of values of K composing the limited sample. Equation (3) can be made dimensionless by dividing both sides by $\overline{K}$. In addition, by denoting the coefficient of variation as C_K, then $C_K = \frac{S_K}{\overline{K}}$ and one obtains

$$\mu_K = 1 \pm \frac{t_{0.975} C_K}{\sqrt{n-1}} \tag{4}$$

The quantity $\frac{t_{0.975} C_K}{\sqrt{n-1}}$ in equation (4) represents the relative uncertainty in determining the true value of K at the 95% confidence level obtained for n different observations of K and may be expressed as

$$E_K = \frac{100 t_{0.975} C_K}{\sqrt{n-1}} \tag{5}$$

where E_K = the relative uncertainty in percent. Values of E_K were computed from the test data for $n = 10$ and these are also given in Table 2.

The values of E_K in Table 2 are presented in the form of bar graphs for the five samplers at the five different towing velocities used for the present tests in Figure 3. It is quite clear from the bar graphs that the greatest uncertainty in determining K for a particular sampler is at the lowest velocity tested and that this varies considerably for different samplers. As velocities increase from 0.30 m/s to 0.45 m/s uncertainties are much reduced and more consistent for all samplers except sampler No.3. It is interesting to note that it is sampler No.3 which has the greatest uncertainty when the towing velocity is 0.30 m/s. One must suspect that this sampler has some unique property which affect its operation at these velocities. At velocities of 0.6 m/s and greater, the uncertainties for all samplers are very similar, having values near 1% and lower for velocities of 0.60 m/s and 0.75 m/s and values between 1% and 1.5% when velocities are at 1.0 m/s.

In spite of the apparent variability in E_K for the five tested samplers, the actual values can be considered to be quite low. It has been shown by Beverage and Futrell (1986) that for values of K as high as 1.5, which represents a deviation from iso-kinetic performance of 50%, the error in measuring the sediment concentration is only -10% for a 0.45 mm sand. This error decreases as the sediment size decreases. For a grain size of 60 mμ, the error is of the order of 1% when $K = 1.5$. In view of these observations, the test results indicate that the calibration of any given DH-48 sampler is sufficiently consistent and that any one calibration is effectively as good as any other at the 95% confidence level.

4.3 Uncertainty in the Value of K for a Group of Samplers

Average values of K for the five samplers tested (i.e. $n = 5$), given as $\overline{K_s}$ and the uncertainties in determining these average values given as E_s were computed for each of the five towing velocities. In order to make a proper comparison with the uncertainty of determining the value of K for a particular sampler, E_K values of this variable were computed for $n = 5$. These new values of E_K were plotted as bar graphs in Figure 4. Superimposed on the bar graphs are the values of E_s for each corresponding towing velocity V_c for each sampler. It can be seen that, when $V_c = 0.30$ m/s, values of E_s are about the same as E_K for sampler numbers 1, 2 and 3 but are considerably larger for sampler numbers 4 and 5. When $V_c = 0.45$ m/s and 0.60 m/s, values of E_s are consistently greater than E_K for all five samplers, whereas when $V_c = 0.75$ m/s and 1.00 m/s, values of E_s and E_K are very similar. The reason for these differences is not known, however, the magnitude of the uncertainties is well within tolerable limits. As a result a calibration for any given sampler can be used for any other sampler of the same type with an uncertainty of less than 10% at the 95% confidence level. This will make it possible to obtain sediment concentration measurements with satisfactory accuracy.

4.4 Effect of Changing Nozzles

An important consideration is the effect that different nozzles of the same type and size may have on the performance coefficient of the DH-48 sampler because of small differences as a result of fabrication variances. It would be of great operational advantage, if small variations in the geometric properties of nozzles do not significantly alter the value of the performance coefficient. If this is the case, then individual calibrations with a particular nozzle will not be necessary. In addition, it will be possible to exchange nozzles in the field without compromising the performance of a given sampler.

The mean values of K (with $n = 10$) obtained with sampler No. A05395 (No.4) and nozzle No. S48-23 from Table 3 were plotted with the results for the same sampler, used with nozzle No. S48-3 from Table 4, in Figure 5. Smooth curves were drawn through the plotted points to facilitate the analysis. The curves show that values of K for the two nozzles differ greatest at the lowest test velocity and this difference decreases as the towing velocity increases. When $V_c = 0.80$ m/s, there is virtually no difference in K obtained with the two nozzles. The reason for this is due to the fact that at low velocities, the flow control is at the nozzle and therefore, small differences in nozzle properties can be expected to have some effect on the sampler performance. As velocities increase, the flow control in the sampler shifts to the air vent and as a result, the effect of nozzle differences decreases (Engel and Droppo, 1992). Considering that nozzle No S48-23 has the value of the velocity coefficient C_v with the greatest deviation from the mean value of a sample of 25 nozzles of the same size and type, the differences in the values of K in Figure 5 are not excessive, particularly given the criteria of Beverage and Futrell (1986).

The uncertainty obtained with the two different nozzles can be compared in Figure 6. Values of uncertainties obtained with nozzle No. S48-23, given as E_n, are superimposed on the bargraphs from Figure 4 for the one case of sampler A05395 (No.4). It can be seen that the uncertainties are generally quite similar and this further confirms that different nozzles can be used with a particular sampler without significant loss in sampling accuracy.

5. CONCLUSIONS

Towing tank tests conducted on the DH-48 suspended sediment sampler with selected 6.2 mm nozzles have resulted in the following conclusions:

The performance coefficient K is greater than 1.0 over most of the operating range of the sampler. As a result the sampler will tend to under-sample the sediment concentration. This sampling deficit is greatest at low velocities and decreases as velocities increase. Tests on five samplers indicate that values of the sampler performance coefficient K can be expected to be in the range $1.0 < K < 1.5$ at the 95% confidence level. Therefore, sampling errors should always be less than 10% for sediment grain sizes less than about 0.5 mm.

The calibration of any given sampler is sufficiently consistent so that any one calibration is effectively as good as any other at the 95% confidence level.

The calibration of any given sampler can be used with any other sampler of the same type with a relative uncertainty of less than 10% at the 95% confidence level. Therefore, sediment concentration measurements can be made without having each sampler calibrated.

The use of different nozzles of the same type and size will not significantly affect the performance of the sediment sampler. Therefore, nozzles of the type prescribed for use with the DH-48 sampler, can be exchanged or interchanged in the field without significant loss in sampling accuracy.

ACKNOWLEDGEMENT

The towing carriage was operated by B. Near and the sampling tests were conducted by C. Bil. The writer is very grateful for their dedication to this study. The writer also wishes to thank P. Zrymiak and F. Lapointe, both of MSD, for their careful review of the original manuscript of this report.

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TABLE 1 Towing Velocities and Sampling Durations

Run	V_c [m/s]	Time [s]
1	0.30	33
2	0.45	21
3	0.60	16
4	0.75	12
5	1.00	09

TABLE 2 Test Data for Standard 6.4 mm Nozzle (No. S48-3)

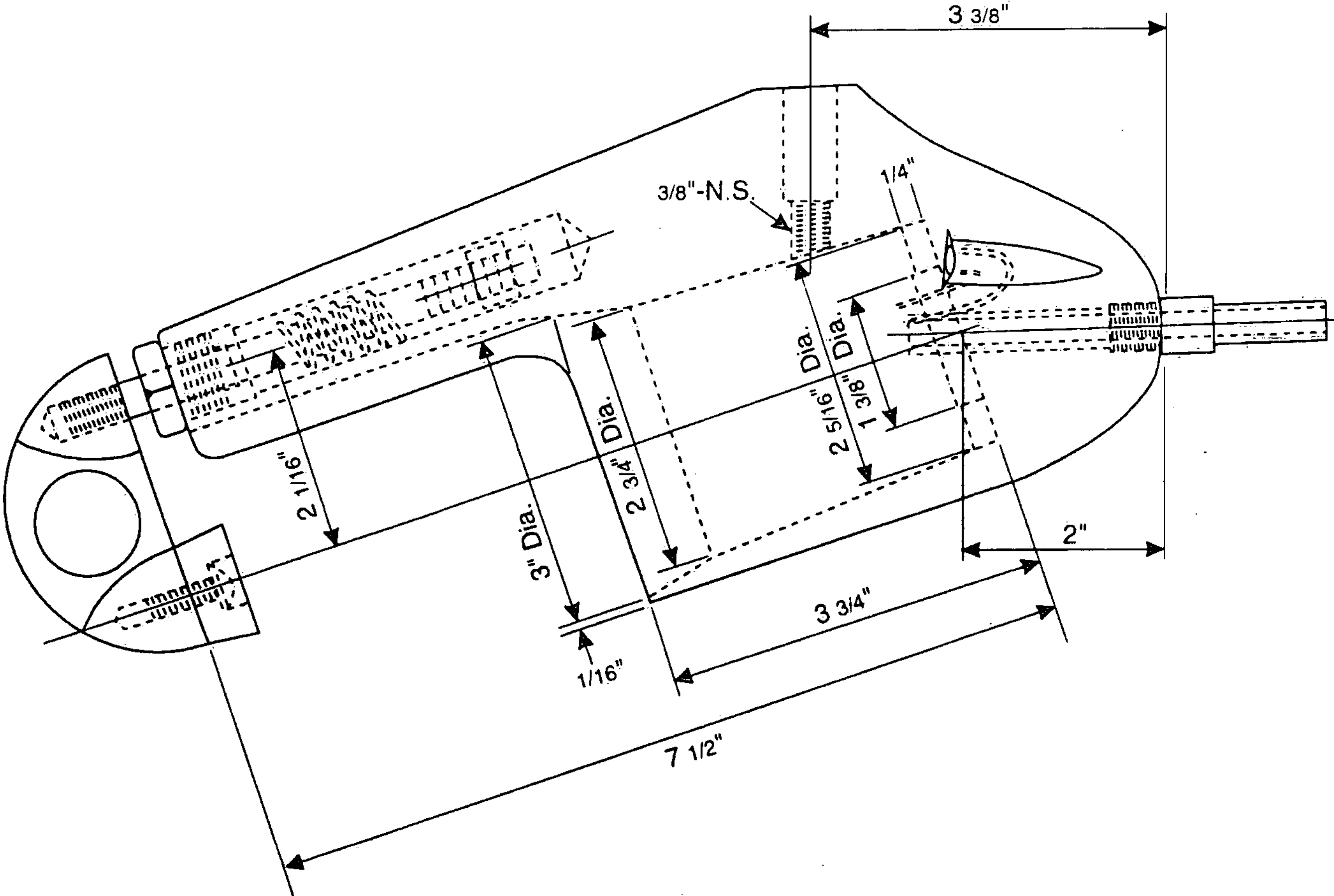
Test	V_c $[m/s]$	$\overline{V_n}$ $[m/s]$	$\overline{K}$	S_K	E_K [%]	Sampler No.
1	0.30	0.392	1.3055	0.0472	2.784	B06616 (No.1)
2	0.45	0.507	1.1268	0.0135	0.922	
3	0.60	0.668	1.1134	0.0082	0.567	
4	0.75	0.812	1.0824	0.0110	0.783	
5	1.00	0.993	0.9929	0.0157	1.218	
6	0.30	0.374	1.2449	0.0438	2.709	A04274 (No.2)
7	0.45	0.498	1.1060	0.0125	0.870	
8	0.60	0.634	1.0573	0.0145	1.056	
9	0.75	0.800	1.0669	0.0164	1.184	
10	1.00	0.990	0.9900	0.0155	1.206	
11	0.30	0.395	1.3168	0.0565	3.304	A40228 (No.3)
12	0.45	0.521	1.1570	0.0310	2.063	
13	0.60	0.685	1.1410	0.0165	1.113	
14	0.75	0.802	1.0689	0.0142	1.023	
15	1.00	1.012	1.0121	0.0196	1.491	
16	0.30	0.421	1.4048	0.0197	1.080	A05395 (No.4)
17	0.45	0.552	1.2265	0.0107	0.672	
18	0.60	0.682	1.1367	0.0109	0.738	
19	0.75	0.798	1.0641	0.0068	0.492	
20	1.00	0.994	0.9937	0.0191	1.480	
21	0.30	0.384	1.2797	0.0096	0.558	A04430 (No.5)
22	0.45	0.507	1.1247	0.0105	0.719	
23	0.60	0.644	1.0732	0.0128	0.918	
24	0.75	0.799	1.0649	0.0072	0.521	
25	1.00	1.005	1.0049	0.0161	1.234	

Standard Nozzle (S48-3) is the nozzle for which the value of C_v is closest to the mean of a sample of 25 nozzles of the same size and type as determined by Engel (1991).

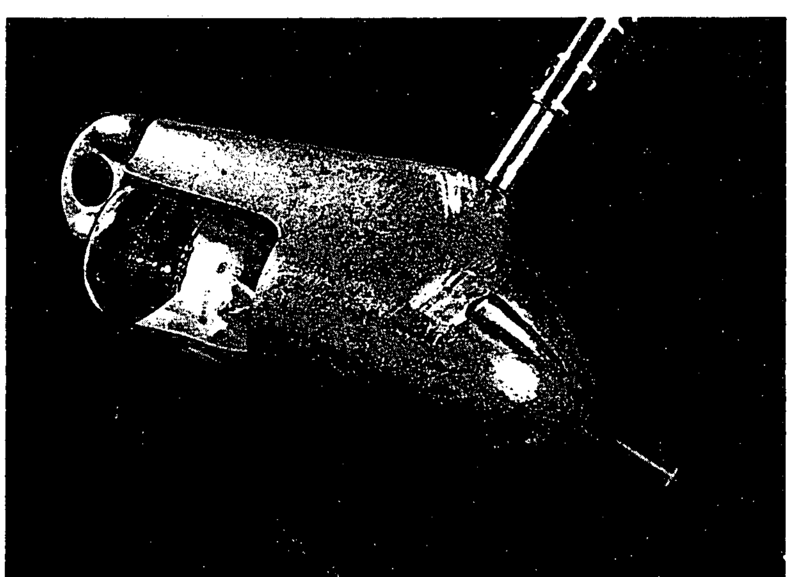
TABLE 3 Test Data for 6.4 mm Nozzle (No. S48-23)

Test	V_c [m/s]	$\overline{V_n}$ [m/s]	$\overline{K}$	S_K	E_n [%]	Sampler No.
26	0.30	0.381	1.2697	0.0057	0.346	A05395 (No.4)
27	0.45	0.517	1.1485	0.0105	0.704	
28	0.60	0.663	1.1043	0.0093	0.649	
29	0.75	0.792	1.0554	0.0088	0.642	
30	1.00	1.001	1.0011	0.0108	0.831	

Nozzle No. S48-23 is the nozzle for which the value of C_v has the largest deviation from the mean value of a sample of 25 nozzles of the same size and type as determined by Engel (1991).



a) SAMPLER SCHEMATIC



b) SAMPLER, SAMPLE BOTTLE, SUSPENSION ROD AND NOZZLE

FIGURE 1. US DH-48 SEDIMENT SAMPLER

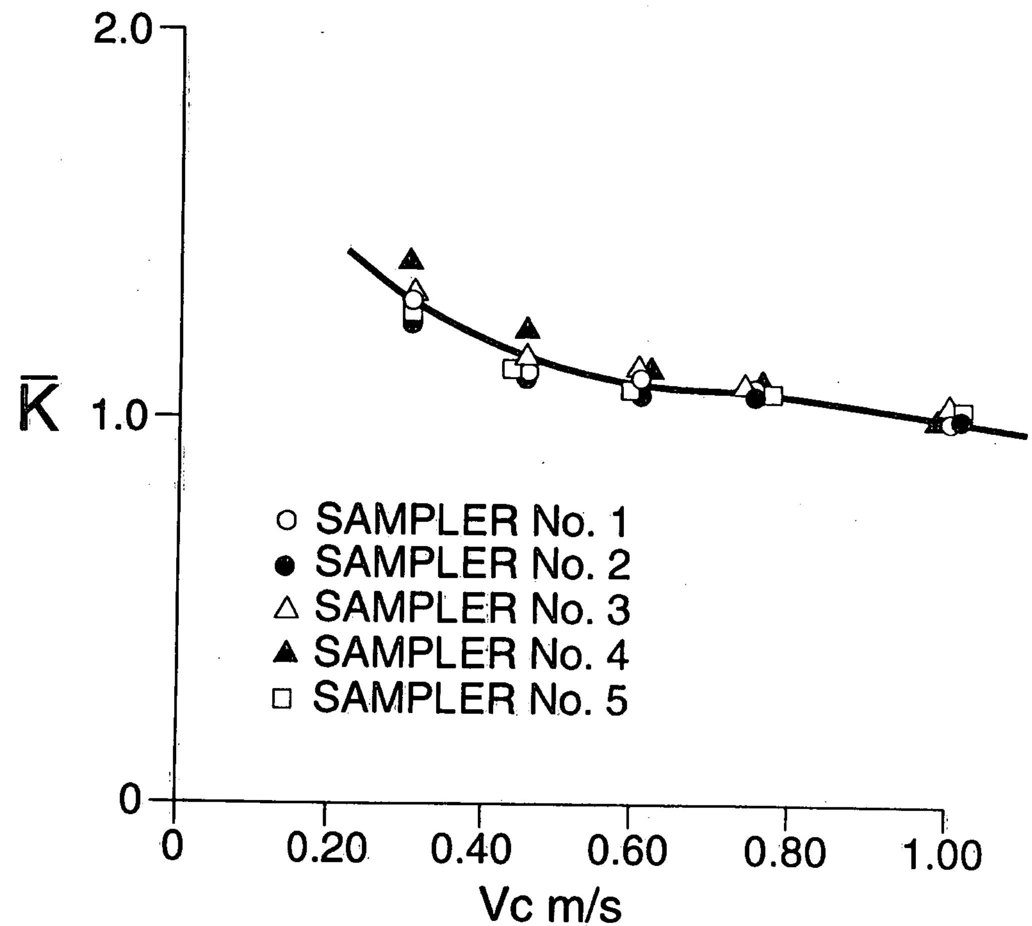


Figure 2 VARIATION OF K WITH TOWING VELOCITY

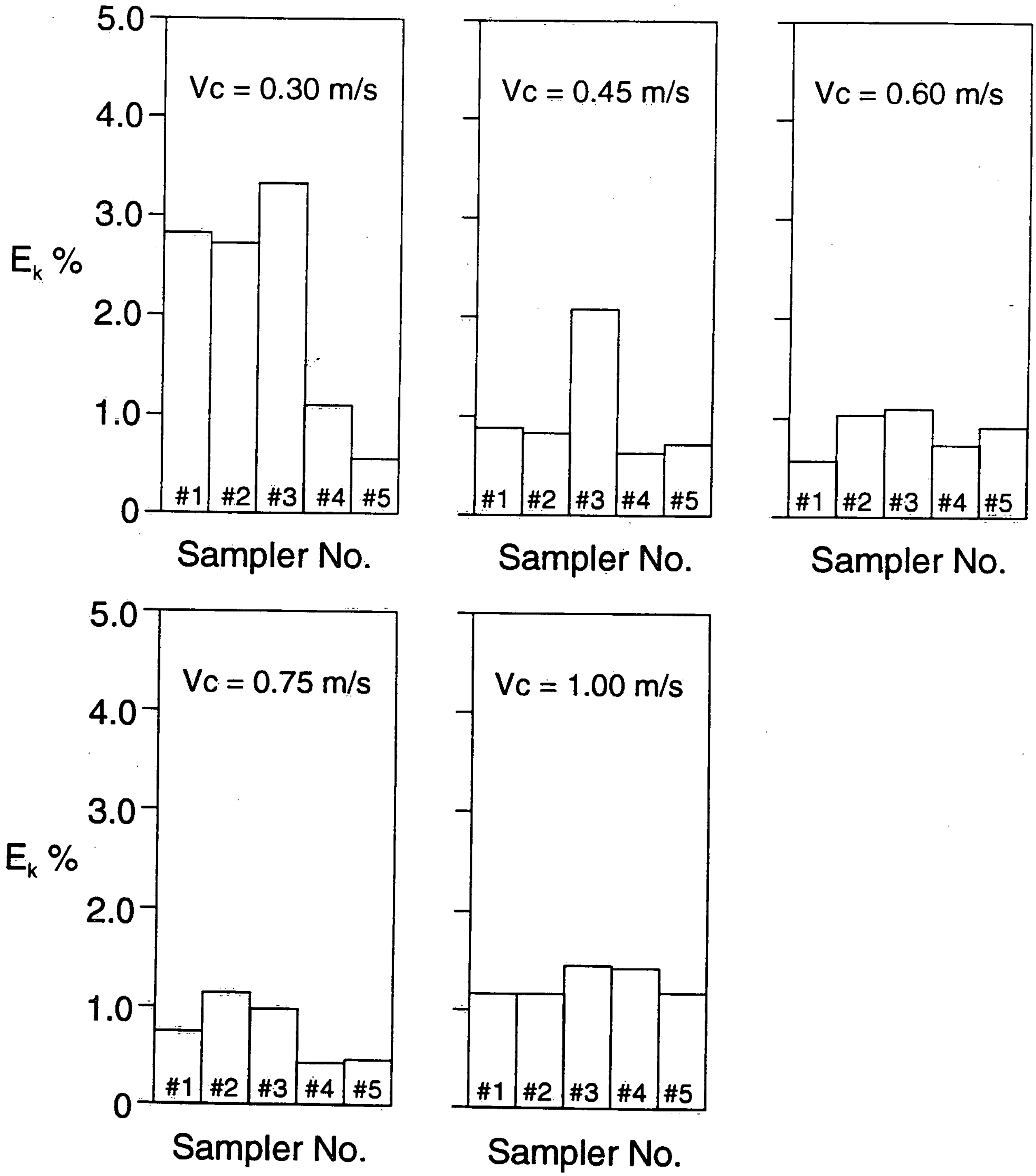


Figure 3 UNCERTAINTY IN K FOR A GIVEN DH-48 SAMPLER WITH 6.2 mm NOZZLE

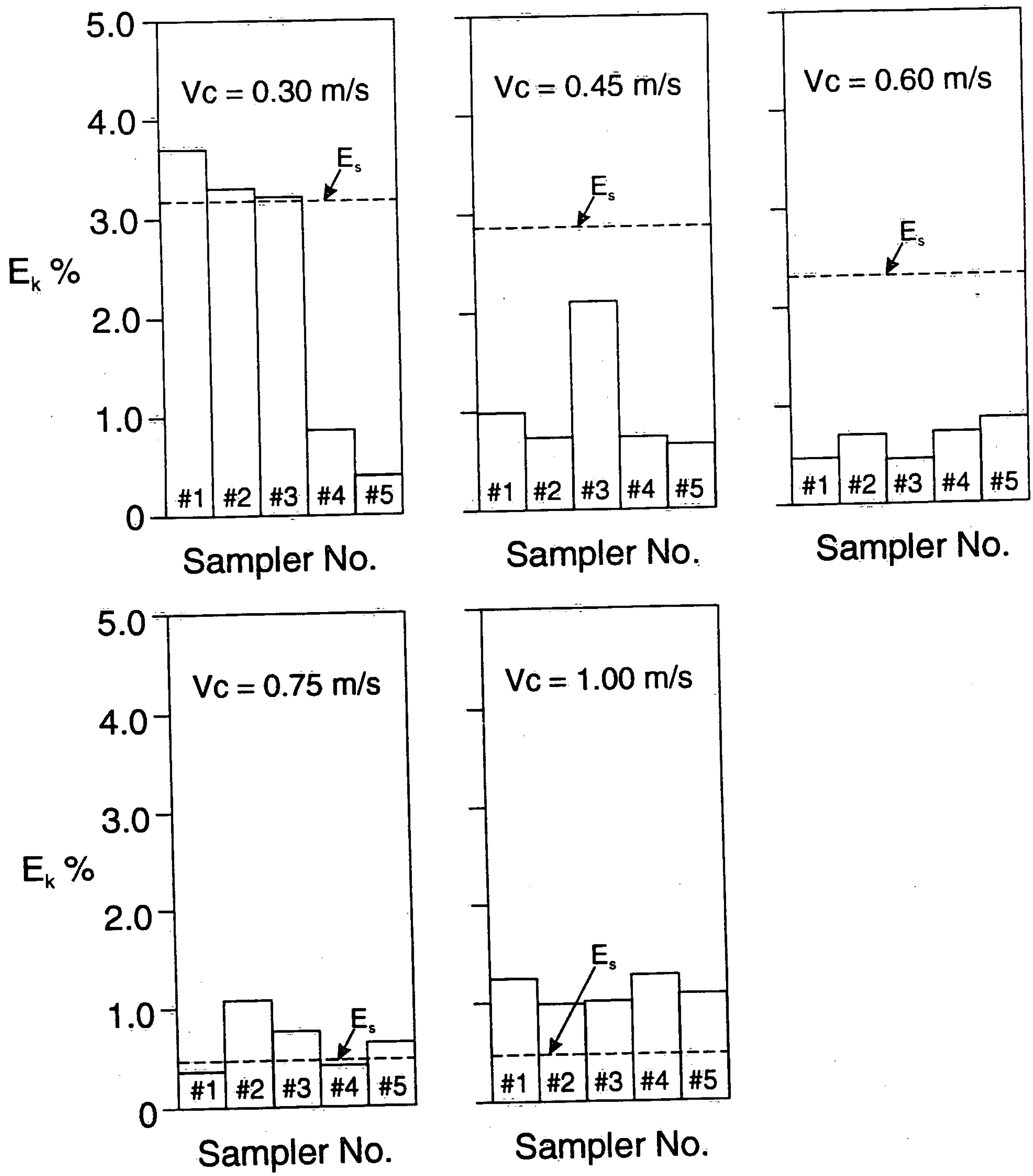


Figure 4 UNCERTAINTY IN K AND Ks FOR DH-48 SAMPLER WITH 6.2 mm NOZZLE

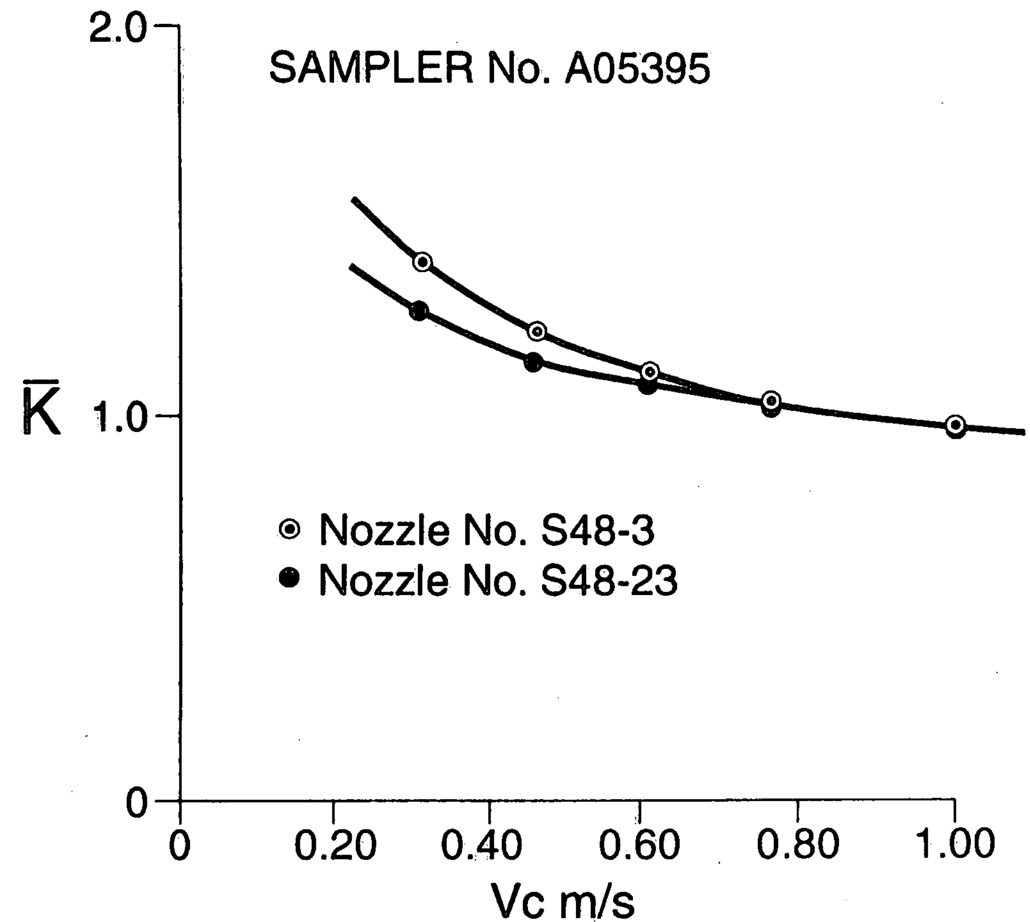


Figure 5 EFFECT OF CHANGING NOZZLES ON K

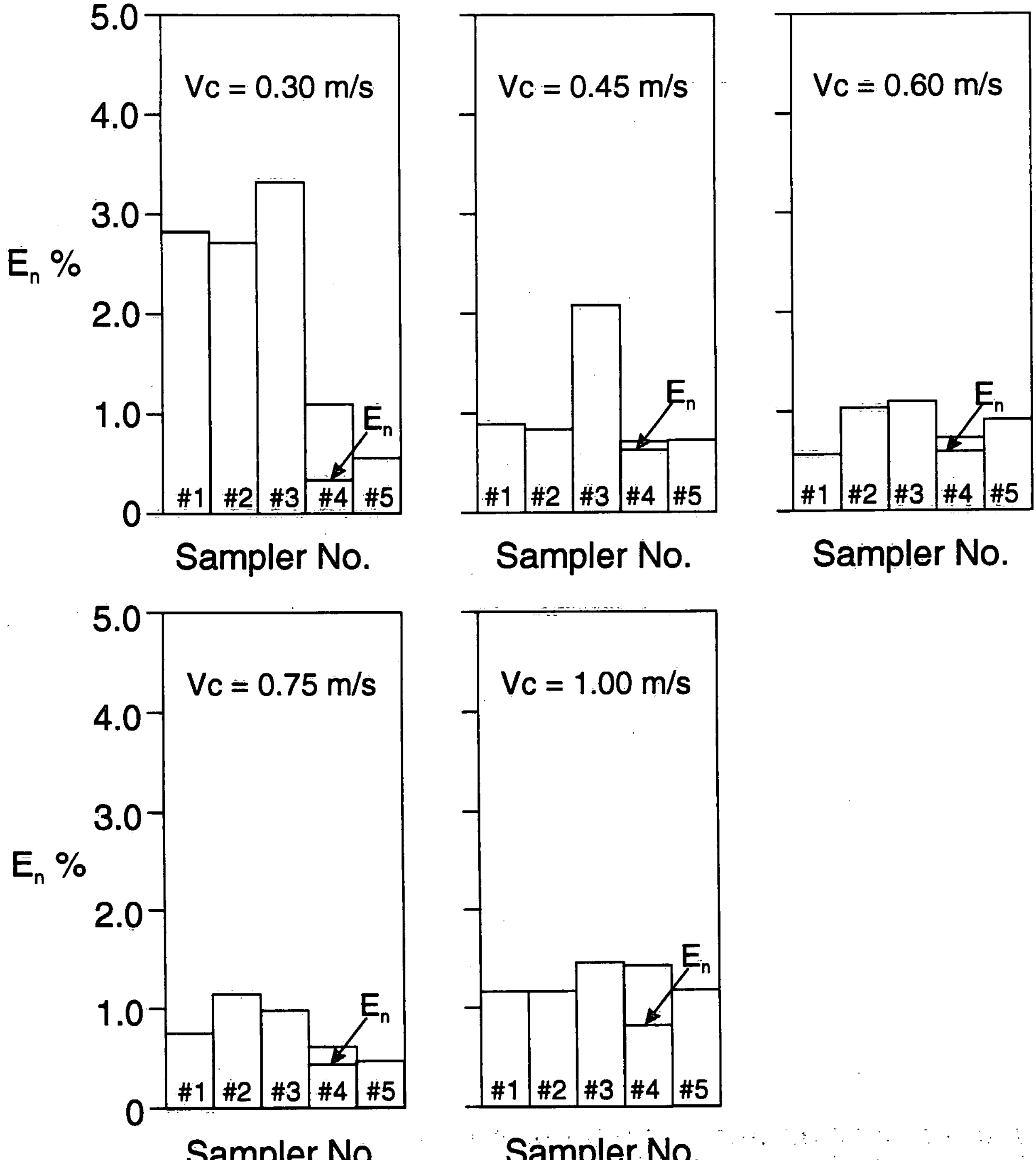


Figure 6 EFFECT OF CHANGING NOZZLES ON UNCERTAINTY IN K FOR A GIVEN SAMPLER

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