An Intercomparison between NEL, CMS/ITRI, SIPAI, KRISS, IPT and CENAM Using a 200 mm Twin Orifice Plate Package in Water

A Report for

National Measurement System Directorate
Department of Trade & Industry
151 Buckingham Palace Road
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1 INTRODUCTION

The project was carried out under the DTI National Measurement System Directorate Flow Programme. An intercomparison between six laboratories was carried out in water, using a 200-mm twin orifice plate assembly consisting of two orifice plate flowmeters separated by a perforated-plate flow conditioner. This assembly had been manufactured in stainless steel at NEL.

This package was calibrated at NEL in March 1999, at CMS/ITRI in Taiwan in March 2001, at SIPAI in China in May 2001, at KRISS in Korea in July/August 2001, at IPT in Brazil in December 2001/January 2002, at CENAM in Mexico in April/May 2002, and finally again at NEL in June/July 2002.

This report summarises the results and gives an overview of the laboratories and test methods. The salient intercomparison graphs are included. The full list of tables of results and associated figures is included. The tables and figures referenced have not been included in this report but are available from NEL in Microsoft EXCEL format on a CD-ROM entitled 'Data from an Intercomparison between NEL, CMS/ITRI, SIPAI, KRISS, IPT and CENAM using a 200 mm Twin Orifice Plate Package in Water'.

2 OBJECTIVES

The objective of this project is to ensure the continuing accuracy of the participating flow calibration laboratories and thereby to ensure that data from one country are acceptable to other countries. To achieve this objective it is necessary to have intercomparison checks between the laboratories, using a flowmetering assembly with repeatable characteristics. These dynamic checks supplement the static traceability chain for an individual laboratory, and identify the systematic differences between laboratories

3 THE LABORATORIES

3.1 NEL

The National Engineering Laboratory (NEL) is an industrial research organisation concerned with many areas of mechanical engineering research. Within NEL the Flow Centre is the holder of the UK National Standards for Flow Measurement. Facilities exist for calibration and research involving water, oil, gas and multiphase flow measurement devices. All the facilities are fully traceable to Primary National Standards and most are accredited by the United Kingdom Accreditation Service (UKAS).

This package was calibrated in the 10-inch test line of the large water flow facility with an additional 43.5*D* and 13*D* of 200-mm NB pipework upstream and downstream of the assembly respectively. Meters are calibrated using a flying start and finish technique against gravimetric standards. Three weigh tanks are available of 1 tonne, 5 tonnes and 50 tonnes. The 5-tonne tank was used for this exercise.

The large water test facility is accredited by UKAS with a best measurement capability uncertainty of 0.1 per cent of flowrate (with a coverage factor of 2). Water/air and water/mercury manometers were used to measure differential pressure.

3.2 CMS/ITRI

CMS/ITRI is the Center for Measurement Standards of the Industrial Technology Research Institute in Taiwan. At CMS/ITRI the expanded uncertainty of flowrate is 0.052 per cent of the indicated value (with a coverage factor of 2.2), and the expanded uncertainty of the differential pressure is 8 Pa (with a coverage factor of 2).

3.3 SIPAI

SIPAI is the Shanghai Institute of Process Automation Instrumentation in China.

3.4 KRISS

KRISS is the Korea Research Institute of Standards and Science.

3.5 IPT

IPT is the Technological Research Institute of the State of São Paulo, in Brazil, and contains several laboratories in technological areas, among them the Flow Laboratory that carries out research related to flow measurement. There are facilities for calibration of water, gas and oil meters in several ranges, accredited by PTB, Germany. In this water meter campaign, the calibration rig used was gravimetric with a 5 tonne weighing tank.

The expanded uncertainty is 0.1 per cent of the indicated value (with a coverage factor of 2) and the expanded uncertainty of the discharge coefficient ranged from 0.25 to 0.38 per cent during this experiment.

3.6 CENAM

The liquid flow facility at the Centro Nacional de Metrología constitutes Mexico's primary standard for liquid flow measurements. The system is based on the static weighing principle with weighbridges of 1.5 tonne and 10 tonne. The intercomparison package was calibrated in the 200-mm test line with an additional 72*D* and 45*D* of 200 mm pipe work upstream and downstream respectively.

The expanded uncertainty in the discharge coefficient increases as the differential pressure reduces, and is in the range 0.09 to 0.36 per cent.

4 THE TRANSFER STANDARD

In each laboratory the 200-mm assembly was installed as shown in Figure 1 (first installation), with additional 200-mm NB pipework upstream and downstream of the assembly respectively, and the flowmeters calibrated simultaneously. The flowmeters were then interchanged as shown in the second installation of Figure 1 and again calibrated simultaneously. In all cases, the orifice plates remained attached to their respective adjacent pipes so that the results would not be affected by separating and reconnecting flanges close to the plates. The tappings on the orifice plates were connected via 'triple-tee' piezometer rings. Dimensions of the orifice plates:

Orifice Plate	S1	S2
Throat diameter (d) mm	102.72	102.71
Pipe diameter (D) mm	205.94	206.25

A mean value of 206.09 mm for the pipe diameter was used in the calculations for both orifice plates. Both orifice plates were fitted with corner, flange, and D and D/2 tappings. Only the flange tappings (4 tappings in each tapping plane) were used in the present tests.

5 THE DATA

All the sets of data from the calibrations and the associated figures are listed in this report. All the tables of data and figures are available in the CD-ROM entitled 'Data from an Intercomparison between NEL, CMS/ITRI, SIPAI, KRISS, IPT and CENAM using a 200 mm Twin Orifice Plate Package in Water'. Only the graphs pertinent to the conclusions are included here.

All the data from the different laboratories are given in Tables 1 – 17 of the CD-ROM. Each set of data has been fitted using an equation of the form

$$C = A + B\left(\frac{10^6}{Re_D}\right)^{0.5}.$$

Each set of data together with a fitted line has been plotted in Figures 2 – 10 of the CD-ROM. So that the data can be compared the line fits of all the data are plotted in Figures 11 – 14.

Because of the range of line temperature used, the data were corrected to 20ºC on the basis that

$$d_{act} = d_{ref}[1 + 0.0000167(T_{act} - 20)],$$

where d_{act} and d_{ref} are the orifice diameters at the actual line temperature, T_{act}, and 20°C respectively.

Data were analysed at Re_D equal to 3.44×10^5 and 1.83×10^5. These values were chosen because they were the upper and lower limits of the range of pipe Reynolds number over which all laboratories collected data. At these Reynolds numbers the values of the lines fitted to each set of data were used to form Youden plots[1,2]. These Youden plots were carried out with the data scaled as a percentage of the average of the seven fitted values and are presented in Figures 15 to 22. The radii of the Youden circles were determined from the method in Wu and Meng[2] because of the small size of sample, and are shown in Table 18.

Data from Orifice Plates		Re_D	Figure No	Radius of Youden circle (per cent)
$S1_{upstream}$	$S2_{downstream}$	3.44×10^5	15	0.30
$S1_{upstream}$	$S2_{downstream}$	1.83×10^5	16	0.22
$S2_{upstream}$	$S1_{downstream}$	3.44×10^5	17	0.41
$S2_{upstream}$	$S1_{downstream}$	1.83×10^5	18	0.42
$S1_{upstream}$	$S2_{upstream}$	3.44×10^5	19	0.11
$S1_{upstream}$	$S2_{upstream}$	1.83×10^5	20	0.13
$S1_{downstream}$	$S2_{downstream}$	3.44×10^5	21	0.16
$S1_{downstream}$	$S2_{downstream}$	1.83×10^5	22	0.18

Table 18 Radii of Youden circles

It is somewhat surprising that the radius of the Youden circle is larger with the downstream data ($S1_{downstream}$ v $S2_{downstream}$) than with the upstream data ($S1_{upstream}$ v $S2_{upstream}$). The more conventional Youden plots ($S1_{upstream}$ v $S2_{downstream}$ and $S2_{upstream}$ v $S1_{downstream}$) have larger

Youden circles. Moreover, in Figs 21 and 22 ($S1_{downstream}$ v $S2_{downstream}$) the data are not scattered about the origin, but are in two groups: it might be that the discharge coefficient in the downstream location depends on the details of the upstream configuration.

The concerns regarding the downstream data came to light as a research project was being completed at NEL to establish the lengths required to meet the compliance test in ISO/FDIS 5167-1:2002[3]. Full details are given in Reference 4, but amongst other data collected were data with a Zanker Flow Conditioner Plate 3*D* upstream of the upstream tappings of a Venturi tube of β = 0.65 with a D-shaped plate upstream of the Zanker Flow Conditioner Plate. Tappings A-A were in the same angular position in the pipe as the middle of the circumference of the open portion of the D on the wall. The calculated shifts in discharge coefficient from those achieved in a long straight pipe are given in Figure 23. Data taken with the Zanker Flow Conditioner Plate 3*D* upstream of the Venturi tube with good flow conditions upstream of the Zanker Flow Conditioner Plate are shown with the distance to the disturbance described as infinity. It is striking how large the shift in discharge coefficient is when the D-shaped plate is too close to the Zanker Flow Conditioner Plate. On the basis of these data, to meet the compliance test it is necessary to have at least 7*D* between the D-shaped plate and the Zanker Flow Conditioner Plate. For the purposes of an intercomparison it is not necessary that the downstream flowmeter should give the same discharge coefficient as the one obtained in a long straight pipe, but it was noted in the test work described in Reference 4 that where the distance between the D-shaped plate and the Zanker Flow Conditioner Plate was too small the pressure loss in the system increased significantly from that where the D-shaped plate and the Zanker Flow Conditioner Plate were well separated. In this intercomparison the upstream fitting was a β = 0.5 orifice plate, the perforated-plate flow conditioner was a Spearman flow conditioner, and the flowmeter was a β = 0.5 orifice plate. However, the distance between the Spearman Flow Conditioner and the orifice plate upstream of it was 5.4*D* and the orifice plate created significantly more blockage than a D-shaped plate, although the distance between the Spearman Flow Conditioner and the orifice plate downstream of it was 15.7*D*. On the basis of this information the downstream Youden plots may be considered to be of less value than the upstream ones. When the next sets of data are collected using this intercomparison package it would be wise to insert an additional length of pipework immediately upstream of the flow conditioner.

6 CONCLUSIONS

The intercomparison using the upstream orifice plate has been successfully carried out with a Youden circle of radius 0.11 per cent for the higher Reynolds number and 0.13 per cent for the lower Reynolds number.

The intercomparison using the downstream orifice plate has been less successful because it appears likely that the flow conditioner was too close to the orifice plate upstream of it.

When the upstream data are compared with the Reader-Harris/Gallagher Equation in ISO 5167-1:1991/Amd. 1:1998[5] the equation lies above the mean of the data by about 0.05 per cent for S1 and by about 0.17 per cent for S2. This is well within the expected uncertainty of the equation.

ACKNOWLEDGEMENTS

The participation of CMS/ITRI, SIPAI, KRISS, IPT and CENAM and the hard work of their staff are gratefully acknowledged.

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4 READER-HARRIS, M. J. Compliance testing of flow conditioners with differential pressure meters. Report no 2002/77 on Project No FDDP02. East Kilbride, Glasgow: National Engineering Laboratory, 2002.

5 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. Measurement of fluid flow by means of pressure differential devices – Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full Amendment 1. ISO 5167-1: 1991/Amd.1:1998. Geneva: International Organization for Standardization.

LIST OF TABLES PROVIDED IN THE CD-ROM ENTITLED 'DATA FROM AN INTERCOMPARISON BETWEEN NEL, CMS/ITRI, SIPAI, KRISS, IPT AND CENAM USING A 200 MM TWIN ORIFICE PLATE PACKAGE IN WATER'.

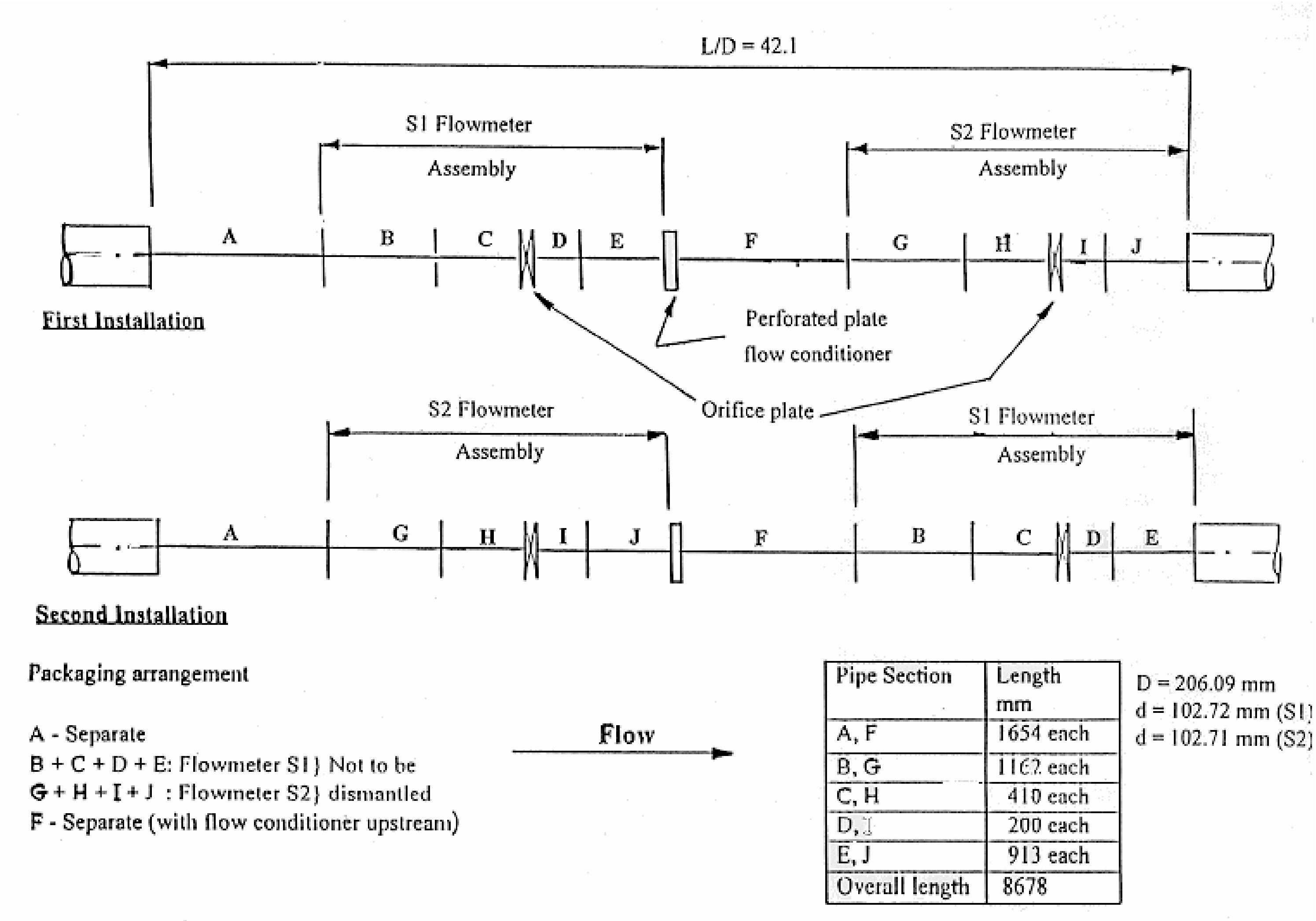
NEL 200 mm STAINLESS STEEL TWIN ORIFICE PLATE TRANSFER STANDARD ASSEMBLY

				Flowmeters		
Table No	Lab / Facility	Date	Test No	Upstream	Downstream	Notes
1	NEL	Mar-99	3269	S1	S2	
2	NEL	Mar-99	3270	S2	S1	
3	NEL	Jun-02	3530	S1	S2	
4	NEL	Jul-02	3535	S2	S1	
5	ITRI	Mar-01	1	S1	S2	
6	ITRI	Mar-01	2	S2	S1	
7	SIPAI	May-01	1	S1	S2	S1 data only
8	SIPAI	May-01	2	S1	S2	S2 data only
9	SIPAI	May-01	3	S2	S1	S2 data only
10	SIPAI	May-01	4	S2	S1	S1 data only
11	KRISS	?	1	S1 S2	S2 S1	
12	IPT	?	1	S1	S2	S1 data only
13	IPT	?	2	S1	S2	S2 data only
14	IPT	?	3	S2	S1	S2 data only
15	IPT	?	4	S2	S1	S1 data only
16	CENAM	Apr-01 May-01	1	S1	S2	
17	CENAM	Apr-01	2	S2	S1	

LIST OF FIGURES PROVIDED IN THE CD-ROM ENTITLED 'DATA FROM AN INTERCOMPARISON BETWEEN NEL, CMS/ITRI, SIPAI, KRISS, IPT AND CENAM USING A 200 MM TWIN ORIFICE PLATE PACKAGE IN WATER'.

NEL 200 mm STAINLESS STEELTWIN ORIFICE PLATE TRANSFER STANDARD ASSEMBLY

Fig No	Lab/ Facility	Date	Test No	Flowmeter	Position
2	NEL	Mar-99 Jun-02	3269 3530	S1	Upstream
3	NEL	Mar-99 Jun-02	3269 3530	S2	Downstream
4	NEL	Mar-99 Jul-02	3270 3535	S2	Upstream
5	NEL	Mar-99 Jul-02	3270 3535	S1	Downstream
6	ITRI	Mar-01		Both	Both
7	SIPAI	May-01		Both	Both
8	KRISS	?		Both	Both
9	IPT	?		Both	Both
10	CENAM	Apr-01 May-01		Both	Both
11	Comparison of calibrations			S1	Upstream
12	Comparison of calibrations			S2	Downstream
13	Comparison of calibrations			S2	Upstream
14	Comparison of calibrations			S1	Downstream
15	Youden plot	$Re_D = 3.44 \times 10^5$		S1 S2	Upstream Downstream
16	Youden plot	$Re_D = 1.83 \times 10^5$		S1 S2	Upstream Downstream
17	Youden plot	$Re_D = 3.44 \times 10^5$		S2 S1	Upstream Downstream
18	Youden plot	$Re_D = 1.83 \times 10^5$		S2 S1	Upstream Downstream
19	Youden plot	$Re_D = 3.44 \times 10^5$		S1, S2	Upstream
20	Youden plot	$Re_D = 1.83 \times 10^5$		S1, S2	Upstream
21	Youden plot	$Re_D = 3.44 \times 10^5$		S1, S2	Downstream
22	Youden plot	$Re_D = 1.83 \times 10^5$		S1, S2	Downstream



Pipe Section	Length mm
A, F	1654 each
B, G	1162 each
C, H	410 each
D, I	200 each
E, J	913 each
Overall length	8678

Figure 1 Installation diagram for NEL 200 mm twin orifice plate transfer standard assembly

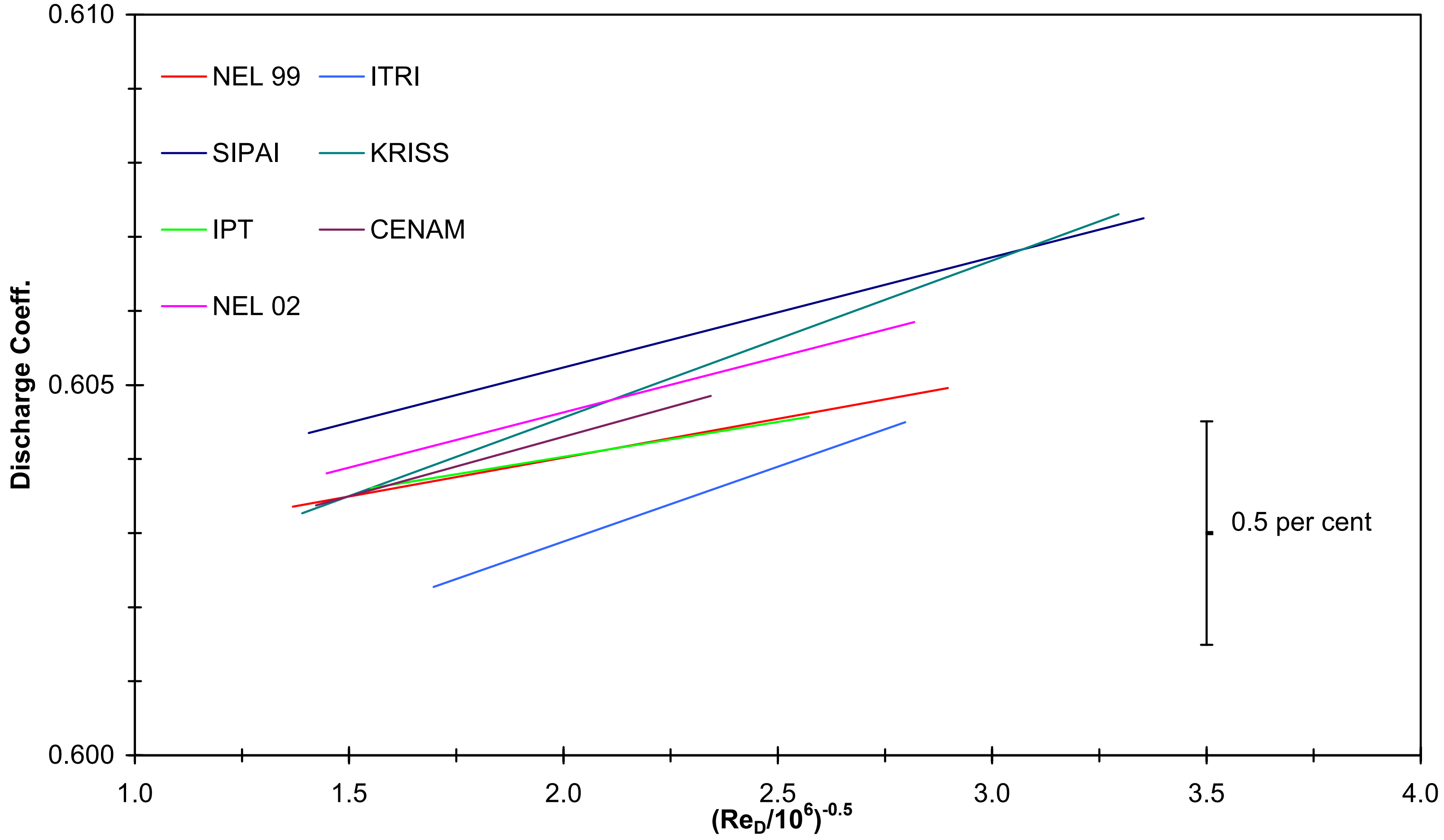


Fig.11 1999/2002: CAL. OF THE NEL 200mm TWIN ORIFICE PLATE ASSEMBLY.
ALL FACILITIES **S1 UPSTREAM**

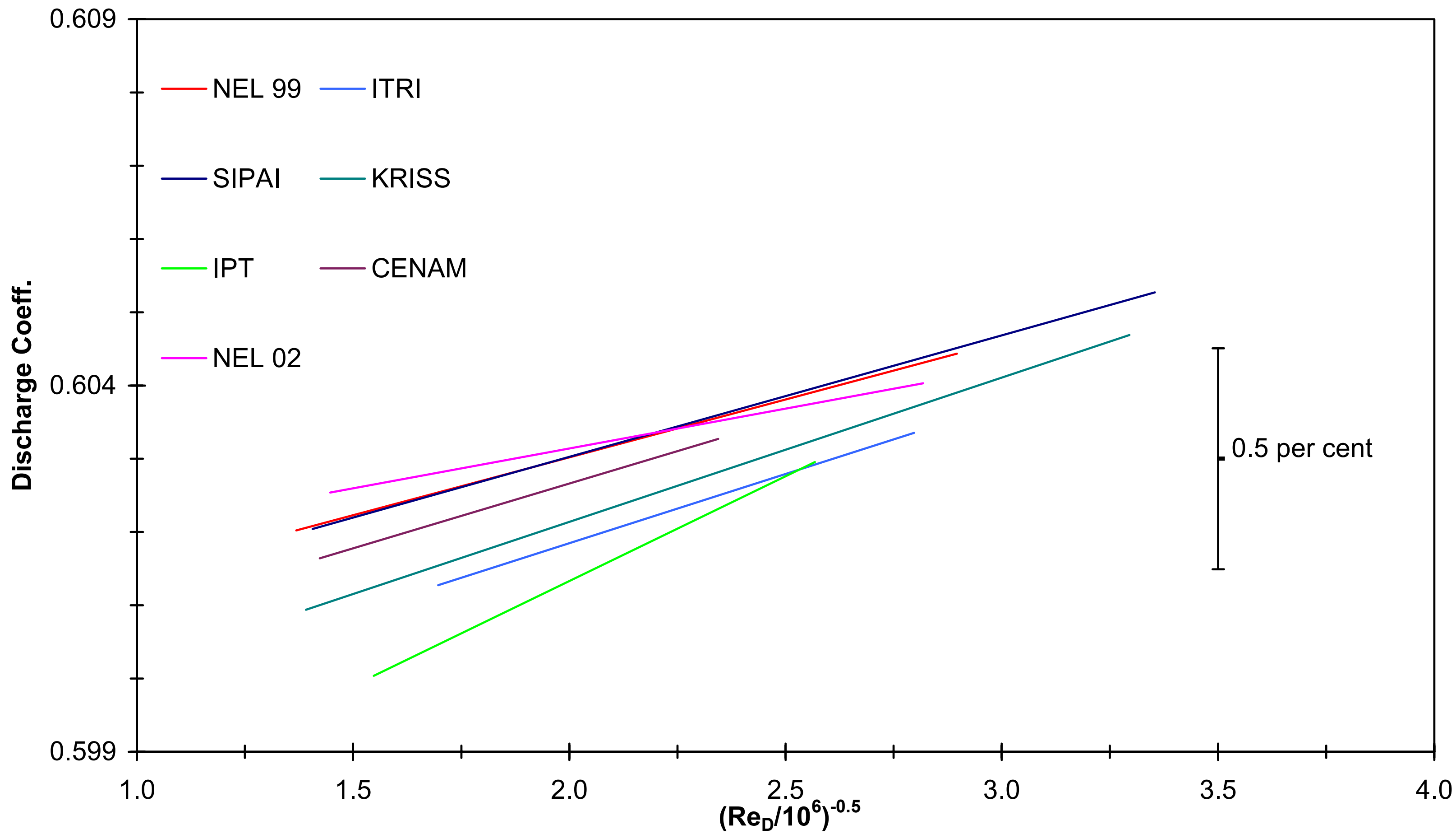


Fig.12 1999/2002: CAL. OF THE NEL 200mm TWIN ORIFICE PLATE ASSEMBLY.
ALL FACILITIES **S2 DOWNSTREAM**

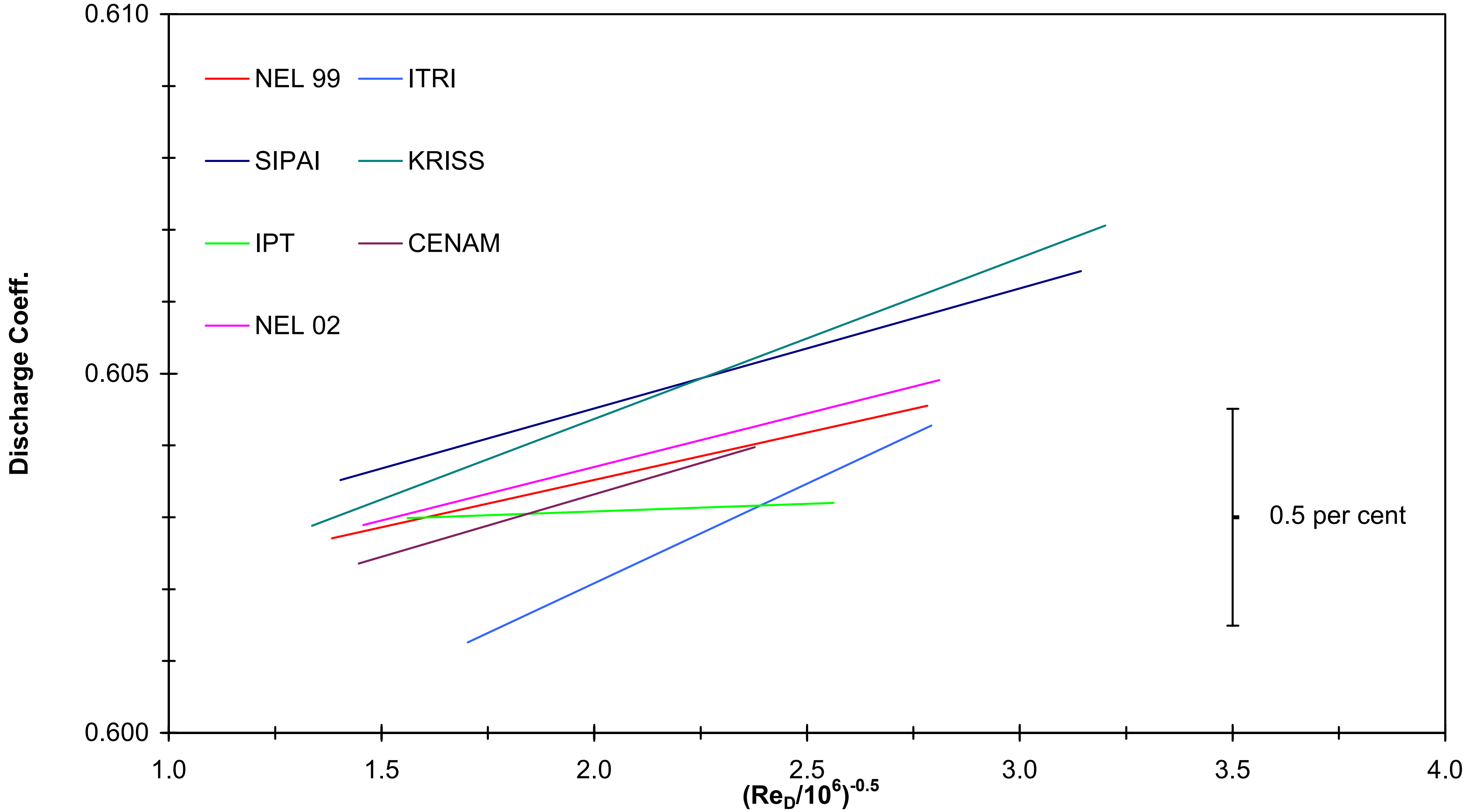


Fig.13 1999/2002: CAL. OF THE NEL 200mm TWIN ORIFICE PLATE ASSEMBLY.
ALL FACILITIES **S2 UPSTREAM**

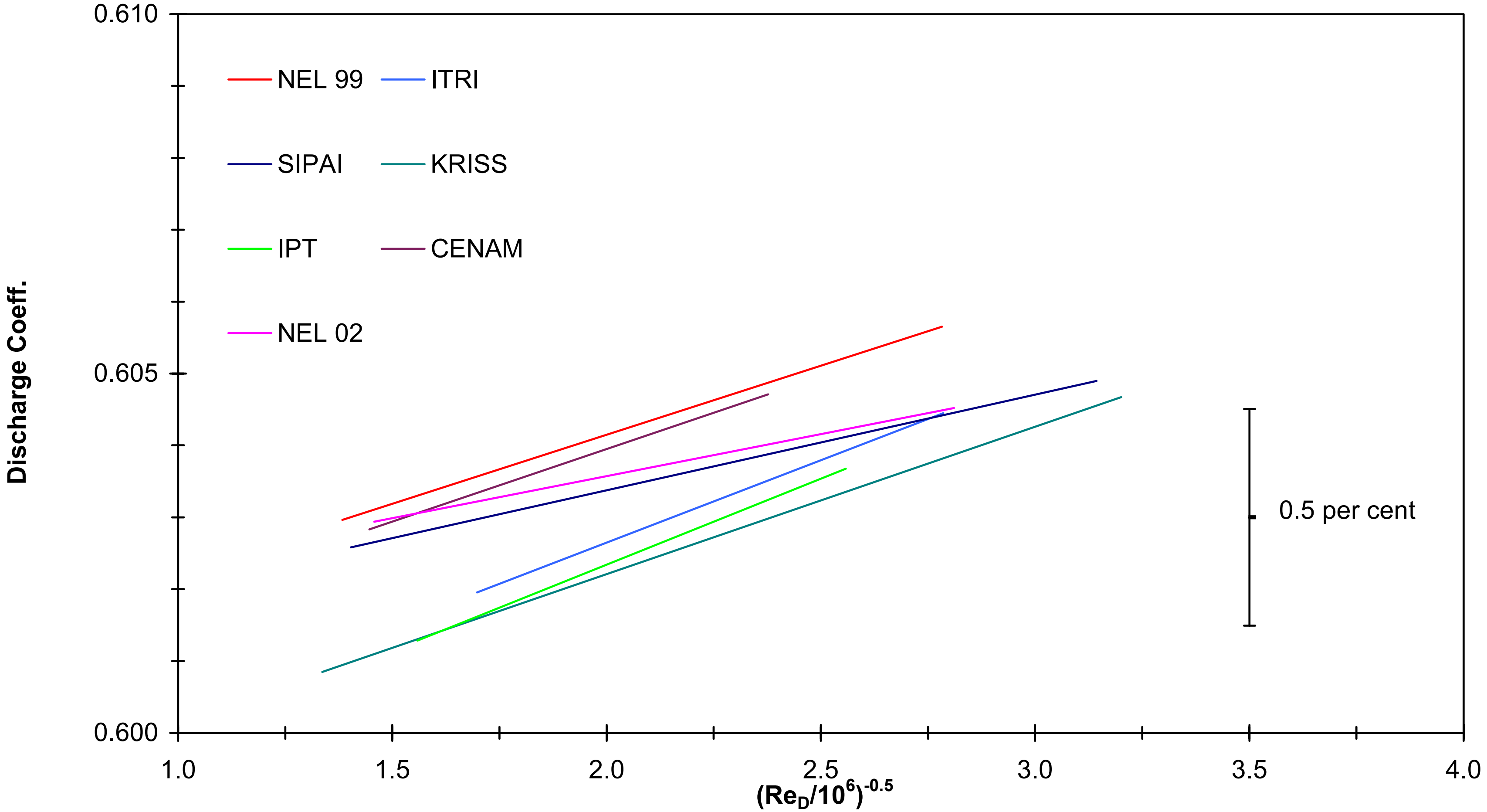


Fig.14 1999/2002 CAL. OF THE NEL 200mm TWIN ORIFICE PLATE ASSEMBLY.
ALL FACILITIES **S1 DOWNSTREAM**

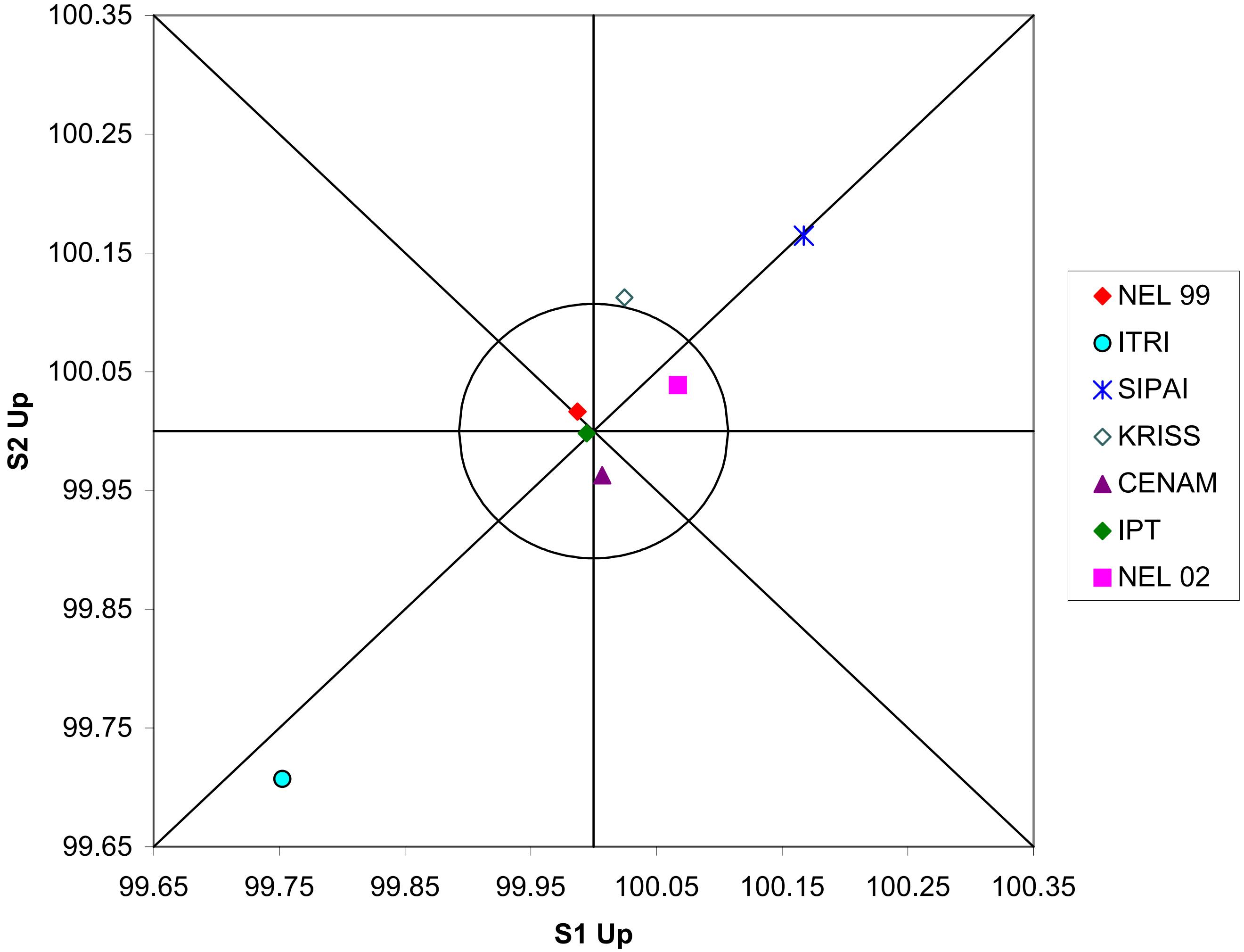


Fig. 19 Youden plot: S1 Up, S2 Up Re_D = 344000

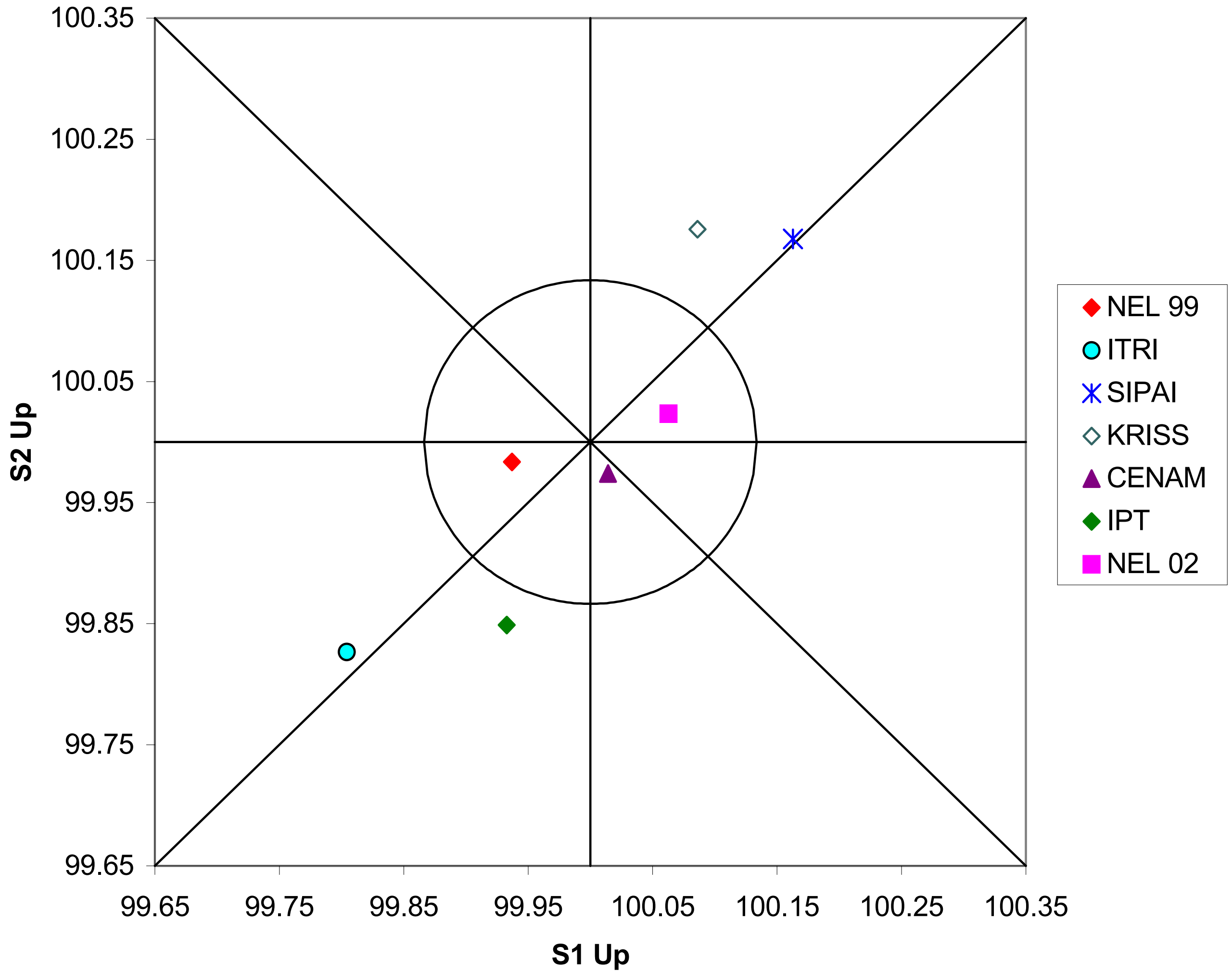


Fig. 20 Youden plot: S1 Up, S2 Up Re_D = 183000

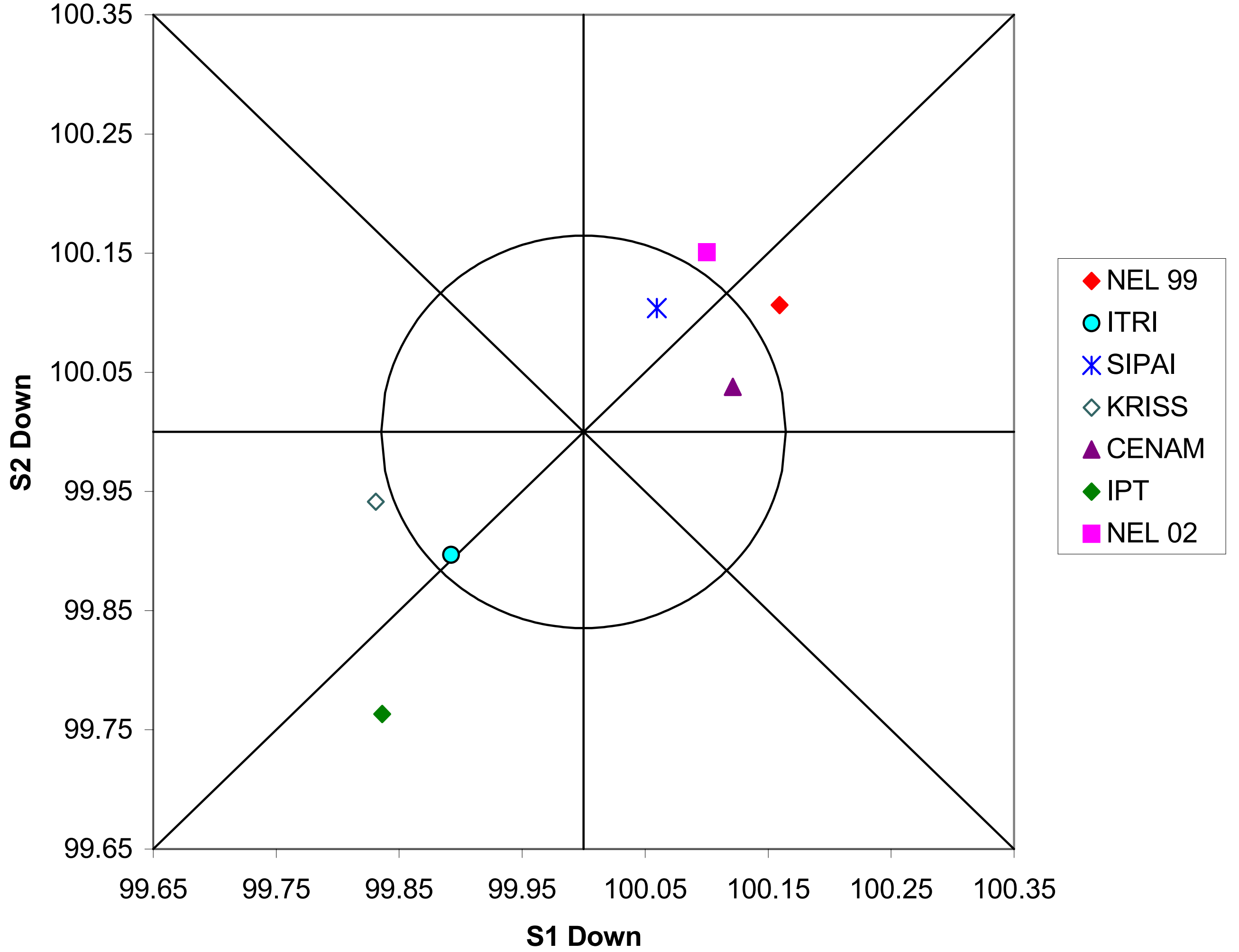


Fig. 21 Youden plot: S1 Down, S2 Down *Re*$_D$ = 344000

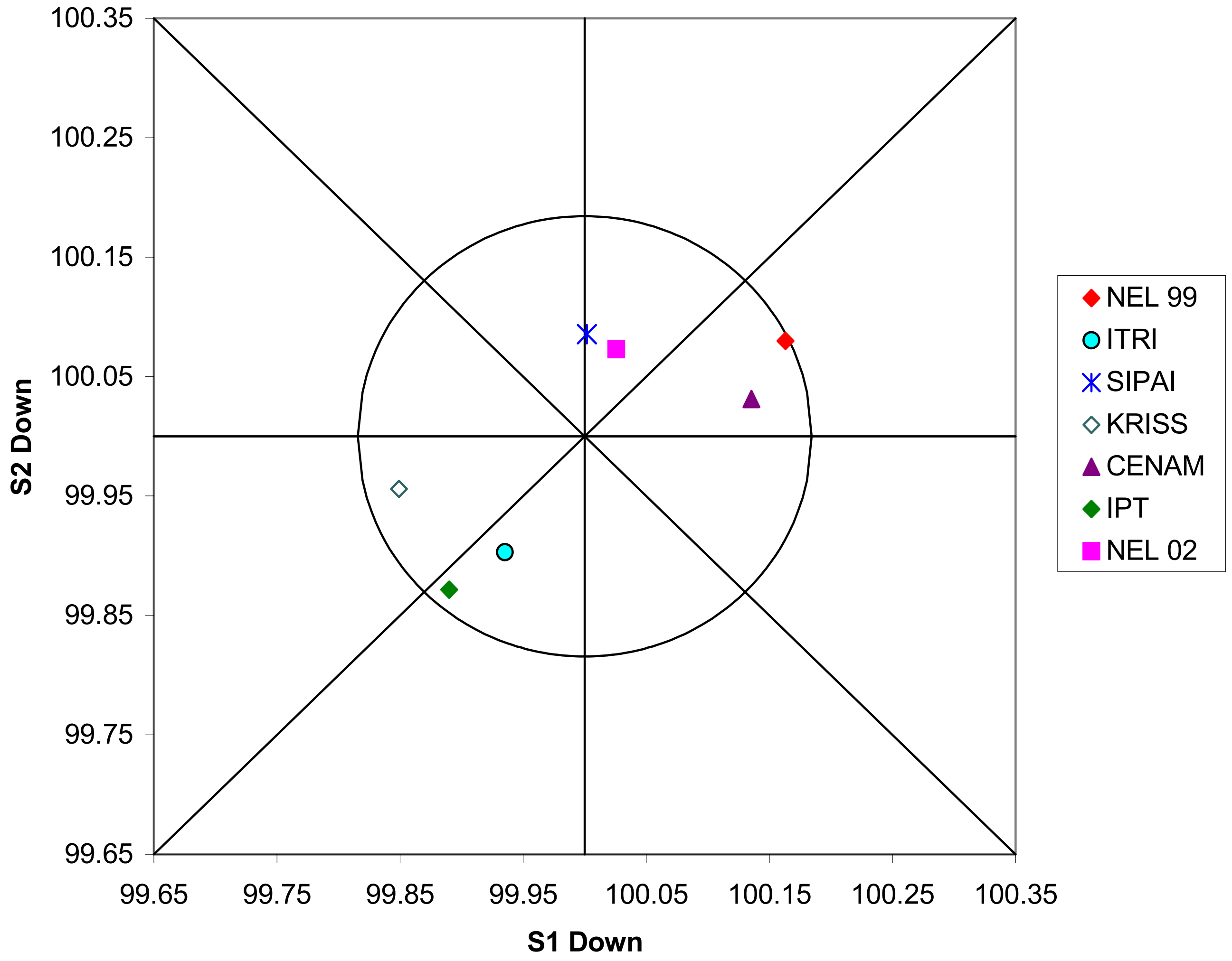


Fig. 22 Youden plot: S1 Down, S2 Down Re_D = 183000

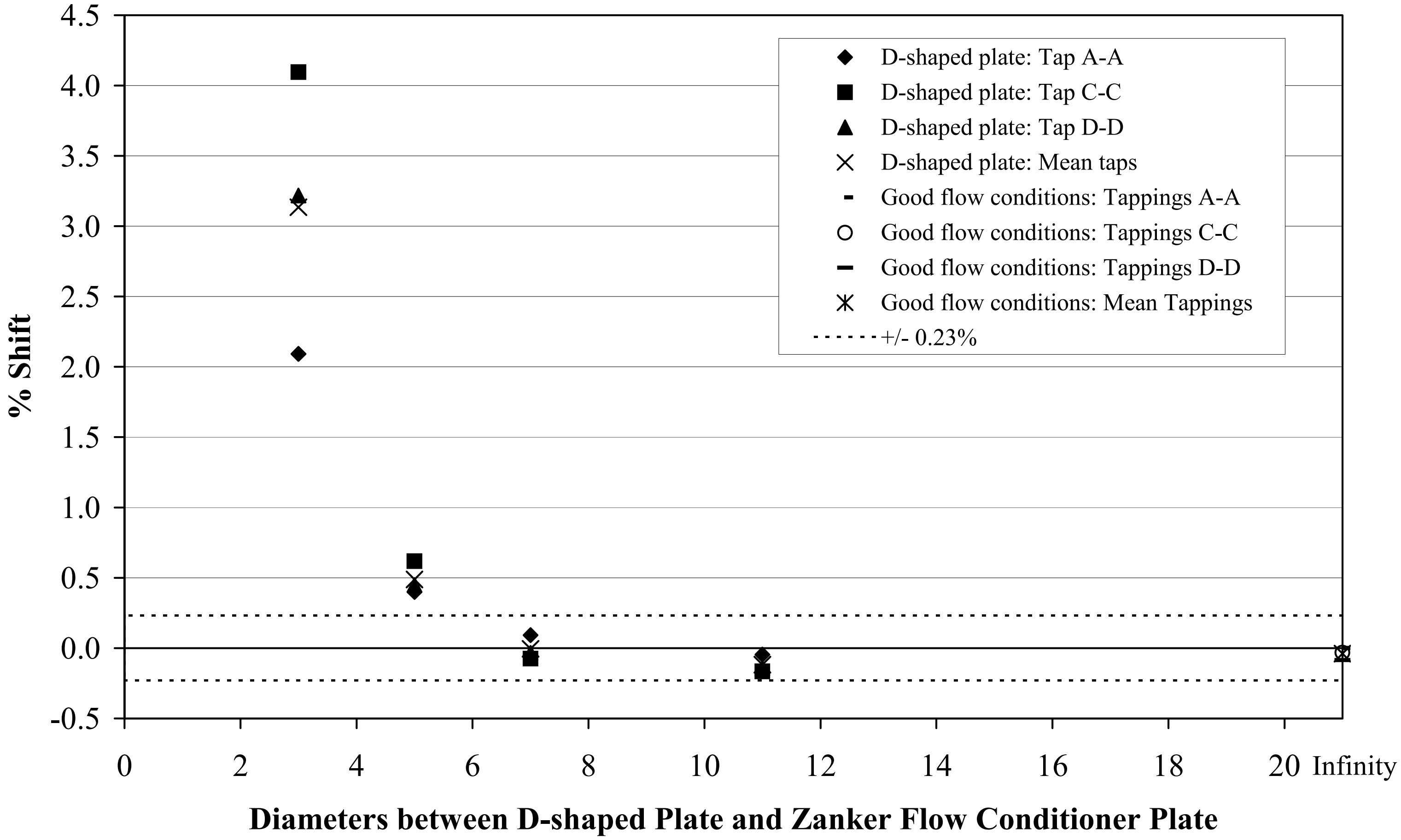


Figure 23. Shift in the discharge coefficient of a Venturi tube ($\beta = 0.65$): Zanker Flow Conditioner Plate 3*D* upstream of the Venturi tube, D-shaped plate (or good flow conditions) upstream of the Zanker Flow Conditioner Plate