Intercomparison tests of gas flow by Bell Prover

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Abstract: This paper describes the intercomparison tests carried out by 10 labs around China from 2003 to 2004. We compared the bell provers with a flow range from 0. 6 to 6 m^3/h by using 2 roots flow meters. Test result and diagram are showed in this paper. We analyzed the influence of temperature control and the seal liquid of bell provers on test.

Keywords: Intercomparison, Bell Prover, Temperature, Seal liquid

In 2003, General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China organized the intercomparison of gas flow among some laboratories all over China, and decided that National Institute of Metrology of China would act as the leading lab. The labs participated are: Beijing Institute of metrology, Liaoning Institute of metrology, Shanxi Institute of metrology, National Institute of Measurement and Testing Technology, Hubei Institute of metrology, Guangdong Institute of metrology, Shanghai Institute of Metrology and Testing Technology, Chongqing Institute of Flow Metrology and Testing Technology and Zhejiang Measurement and Test Institute for Quality and Technique Supervision.

1. Intercomparison Design

（1）   Flow standard used: 100L bell prover
（2）   The flow range of intercomparison: (0. 6~6) m^3/h
（3）   The transfer standard for intercomparison: 2 gas roots flow meters (serial No.: 324410，324411)，

Repeatability: 0.2%, accuracy: 0.5%.
（4）   The mode of transfer
Whenever one or two labs completed the test, the transfer standards will return to the leading lab. The leading lab will test and check them to guarantee the effectiveness of the comparing data.
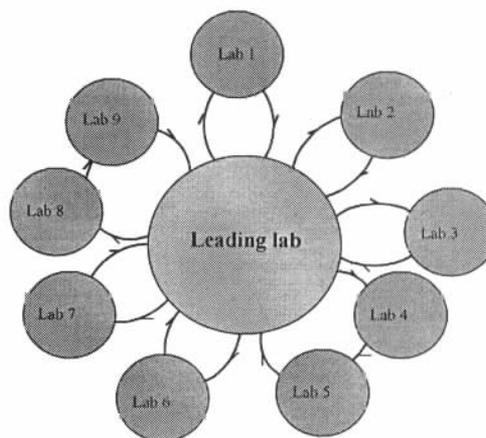

Fig. 1 Route for the intercomparison

2. Mathematic Model and Calculation Process

The intercomparison result is the instrument coefficient of the flow meter. We took the universal calculating method of international

intercomparison, i.e. took the weighted average of measurements from labs as the reference value for the intercomparison as that shown in formula 1.

$$K_i = \frac{\sum\limits_{j=1}^{n} \dfrac{K_{ji}}{U_{ji}^2}}{\sum\limits_{j=1}^{n} \dfrac{1}{U_{ji}^2}} \qquad (1)$$

Where, K_{ji} is the instrument coefficient, i is the flow point and j is the lab, K_i is reference value, weighted average instrument coefficient, U_{ji} is expanded uncertainty of the measurement, which is the self-evaluated data from each lab, which are given in table 1.Uncertainty of reference value is:

$$u_i = \sqrt{u_{ri}^2 + u_{ei}^2} \qquad (2)$$

Where, u_i is uncertainty of reference value. u_{ei} is uncertainty of stability of reference value. During the intercomparison, the leading lab tested the transfer standards for several times, and took half of the relative maximum difference of measurements as the expanded uncertainty of stability of the flowmeter and considered them as being distributed evenly, as for the testing data, refer to table 2. u_{ri} is Uncertainty of testing capability of lab will be calculated according to formula 3

$$u_{ri} = \sqrt{\frac{1}{\sum\limits_{j=1}^{N} \dfrac{1}{u_{ji}^2}}} \qquad (3)$$

We evaluated the intercomparison measuring results of labs through the instrument coefficient K_{ji}, average instrument coefficient K_i, uncertainty of each lab U_{ji} and uncertainty of reference value U_i. Criterion for intercomparison results is:

$$E_{ni} = \frac{K_{ji} - K_i}{\sqrt{U_{ji}^2 + U_i^2} \times K_{ji}} \times 100\% \qquad (4)$$

$|E_n| < 1 ——$ Acceptable;

$|E_n| > 1 ——$ Unacceptable.

3.Analysis on the Intercomparison Technology

（1）About temperature control and correction
During the intercomparison, most labs corrected the gas temperature in the bells and that of flow meters. Other labs thought that the gas temperature in the bells is the same with that at the flowmeter, hence they didn't correct the temperature.

First, we considered that the temperature in the bell prover may be different from that before the flow meters, however, as each lab measured the temperature in the bell through the hole in the exhaust pipe, this could not represent the temperature in the bell prover; as the temperature-measuring point is near to the flow meter, when no normal-close electromagnetic valve is used before flow meter, one may think that the temperature difference was low. Additionally, as the thermometer used for measuring the temperature in the bell prover is different from that for measuring the temperature before the flow meter, the uncertainty due to the difference of measuring instruments will also produce un-negligible influence on the calculated results. Therefore we processed the data from each lab without temperature correction as the calculation results (refer to table 6). From the table, we can see that value of En is somewhat reduced in average way, therefore we can deduce that the correctness of temperature measurement and calculation is a source for measurement error. Therefore, we thought that the data without temperature correction are more reasonable.

We thought that one should make the gas

temperature in the bell consistent with the ambient temperature as much as possible, so as to reduce the heat exchange due to temperature gradient. The measures taken are: changing the sealing liquid into oil; prolonging the maintaining time after the bell is lifted; changing the blower-lifting way into chain-lifting one; adding transient container so that the gas temperature is near to the ambient temperature before entering the bell. The effectiveness of different ways are subject to further intensive test and research.

（2）About the sealing liquid

According to the current verification regulation, the sealing liquid can be water or oil. But until recent, there is no research about the difference of the two sealing ways has been done. Two labs carried out this kind of test during this intercomparison, and preliminary conclusions have been obtained.

Test with different liquid on the same bell prover was conducted. First fill water as sealing liquid into bell prover, verify the bell prover and do some relative test to the flow meter; then change the sealing liquid into oil and complete the same test. Compare the difference between the two tests. From the test results we can get: when a 100L bell prover is verified by static volumetric method, the relative difference of the scale length is 0.39%: the oil scale is shorter and water scale is longer. The results of another lab also showed that the oil scale is shorter and water scale longer, the difference between them is 0.22%.

Table 7 shows the tests carried by the National Institute of Metrology with different sealing liquid. The result shows that the average difference is 0.4%. The instrument coefficient of water is bigger, that of oil is smaller. A preliminary conclusion can be get from this test: when the bell prover with different liquid is verified by static volumetric method, it will have a difference of 0.3%~0.4%. Further test and analysis should be done to find out the reasons.

4.Intercomparison Data and Result

Table 1. Uncertainty of measurements from different labs

Flow	U （k=2） Meter No.: 324410									Unit: %
(m³/h)	Leading lab.	1	2	3	4	5	6	7	8	9
6	0.23	0.29	0.51	0.65	0.24	0.21	0.70	0.32	0.26	0.34
4.8	0.23	0.29	0.51	0.65	0.22	0.21	0.70	0.34	0.26	0.34
3	0.23	0.29	0.51	0.65	0.23	0.21	0.70	0.32	0.26	0.34
1.2	0.23	0.29	0.51	0.65	0.22	0.21	0.70	0.34	0.26	0.34
0.6	0.23	0.29	0.51	0.65	0.24	0.21	0.70	0.33	0.26	0.34
Flow	U （k=2） Meter No.: 324411									Unit: %
(m³/h)	Leading lab.	1	2	3	4	5	6	7	8	9
6	0.23	0.29	0.51	0.65	0.24	0.23	0.76	0.33	0.26	0.29
4.8	0.23	0.29	0.51	0.65	0.23	0.23	0.76	0.34	0.26	0.29
3	0.23	0.29	0.51	0.65	0.22	0.23	0.76	0.33	0.26	0.29
1.2	0.23	0.29	0.51	0.65	0.23	0.23	0.76	0.33	0.26	0.29

Table 2. Test on stability of the transfer standards

Serial No. of the transfer standard: 324410

Date / Flow	10.6	11.14	11.26	12.12	12.25	2.3	3.16	Average	Max.	Min.	U (%)	u (%)
6.0 m³/h	8603.69	8603.91	8607.26	8583.01	8590.60	8590.33	8605.63	8597.77	8607.26	8583.01	0.14	0.08
4.8 m³/h	8611.28	8612.55	8617.34	8583.98	8600.59	8596.92	8615.03	8605.39	8617.34	8583.98	0.19	0.11
3.0 m³/h	8600.34	8600.09	8600.77	8581.04	8586.31	8579.06	8602.62	8592.89	8602.62	8579.06	0.14	0.08
1.2 m³/h	8597.83	8615.02	8605.69	8585.62	8588.58	8587.30	8601.35	8597.34	8615.02	8585.62	0.17	0.10
0.6 m³/h	8577.10	8584.07	8583.06	8563.09	8561.55	8568.41	8588.07	8575.05	8588.07	8561.55	0.15	0.09

Serial No. of the transfer standard: 324411

Date / Flow	10.6	11.14	11.26	12.12	12.25	2.3	3.16	Average	Max.	Min.	U (%)	u (%)
6.0 m³/h	8572.72	8566.13	8607.33	8569.15	8563.35	8571.02	8555.12	8572.12	8607.33	8555.12	0.30	0.18
4.8 m³/h	8576.46	8571.63	8611.53	8569.85	8570.18	8572.04	8561.74	8576.20	8611.53	8561.74	0.29	0.17
3.0 m³/h	8574.04	8569.00	8603.07	8566.57	8564.54	8570.13	8557.39	8572.11	8603.07	8557.39	0.27	0.15
1.2 m³/h	8567.71	8567.80	8593.79	8562.65	8565.14	8568.05	8557.76	8568.99	8593.79	8557.39	0.21	0.12
0.6 m³/h	8552.85	8555.75	8583.65	8546.60	8551.46	8555.03		8557.56	8583.65	8546.60	0.22	0.12

Table 3. Reference value and its uncertainty （0.6 m³/h~6.0 m³/h）

Serial No.: 324410

Flow	Average instrument coefficient	u_r	u_e	u
(m³/h)	(imp/m³)	(%)	(%)	(%)
6.0	8601.80	0.05	0.08	0.09
4.8	8613.30	0.05	0.11	0.12
3.0	8598.72	0.05	0.08	0.09
1.2	8598.09	0.05	0.10	0.11
0.6	8568.08	0.05	0.09	0.10

Serial No.: 324411

Flow	Average instrument coefficient	u_r	u_e	u
(m³/h)	(imp/m³)	(%)	(%)	(%)
6.0	8569.74	0.05	0.18	0.19
4.8	8573.04	0.05	0.17	0.18
3.0	8575.89	0.05	0.15	0.16
1.2	8569.20	0.05	0.12	0.13
0.6	8557.59	0.05	0.12	0.13

Table 4. Summary of En values from different labs when the reference value is the weighted average value

The instrument coefficient is the average weighted value										Serial No.: 324410
Flow	Leading lab	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
6	0.07	-0.64	0.44	0.84	2.95	-2.53	1.05	0.42	0.07	-0.95
4.8	-0.07	-0.68	0.49	0.68	2.63	-2.04	0.30	0.25	0.16	-1.15
3	0.06	-0.53	0.80	0.87	2.54	-2.37	0.82	0.50	-0.04	-1.03
1.2	-0.01	-0.40	1.23	0.73	2.21	-2.45	0.73	0.52	0.27	-1.12
0.6	0.34	-0.04	1.41	1.35	0.66	-2.07	-0.40	0.85	0.81	-0.99

The instrument coefficient is the average weighted value										Serial No.: 324411
Flow	Leading lab	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 9
6	0.08	-0.37	0.76	0.91	0.76	-0.62	-0.70	0.43	0.24	-0.97
4.8	0.10	-0.35	0.65	1.10	1.14	-1.03	-0.41	0.32	0.27	-1.08
3	-0.06	-0.39	0.76	0.98	1.47	-1.16	-0.56	0.40	0.04	-1.07
1.2	-0.05	-0.33	1.03	0.76	1.69	-1.25	-0.60	0.59	0.16	-1.53
0.6	-0.16	-0.33	1.00	0.99	1.78	-1.04	-0.79	0.46	0.11	-1.80

Table 5. Arithmetical average of instrument coefficients of flowmeters

			Serial No.: 324410		
Flow	Average instrument coefficient	U_r	U_e		U
(m³/h)	(imp/m³)	(%)	(%)		(%)
6.0	8613.74	0.10	0.28		0.23
4.8	8618.49	0.10	0.39		0.40
3.0	8610.19	0.11	0.27		0.29
1.2	8610.03	0.10	0.34		0.36
0.6	8579.34	0.11	0.31		0.33
			Serial No.: 324411		
Flow	Average instrument coefficient	U_r	U_e		U
(m³/h)	(imp/m³)	(%)	(%)		(%)
6.0	8573.02	0.11	0.61		0.62
4.8	8578.18	0.11	0.58		0.59
3.0	8579.17	0.10	0.53		0.54
1.2	8572.39	0.10	0.42		0.43
0.6	8559.71	0.10	0.43		0.44

Table 6. Summary of En values from different labs without temperature correction when the instrument coefficient is the weighted average value

					Serial No.: 324410					
Flow	Leading lab.	1	2	3	4	5	6	7	8	9
6	-0.01	-0.60	0.30	0.80	1.71	-1.60	0.94	0.24	0.00	-0.87
4.8	-0.02	-0.55	0.39	0.67	1.73	-1.26	0.38	0.19	0.15	-0.93
3	-0.09	-0.59	0.55	0.79	1.57	-1.51	1.13	0.30	-0.15	-1.01
1.2	-0.13	-0.44	0.88	0.64	1.29	-1.68	0.83	0.48	0.09	-0.96
0.6	0.19	-0.06	1.04	1.28	0.38	-1.37	-0.76	0.88	0.53	-0.82
					Serial No.: 324411					
Flow	Leading lab.	1	2	3	4	5	6	7	8	9
6	0.16	-0.23	0.63	0.88	0.64	-0.16	-0.69	0.08	0.27	-0.63
4.8	0.17	-0.16	0.54	1.05	0.91	-0.52	-0.66	0.06	0.29	-0.69
3	0.09	-0.20	0.64	0.97	1.15	-0.59	-0.70	0.29	0.16	-0.62
1.2	0.16	-0.12	0.89	0.83	1.34	-0.67	-0.83	0.04	0.30	-0.91
0.6	0.06	-0.08	0.85	1.03	1.35	-0.51	-0.77	0.07	0.24	-1.11

Table 7. Tests on flow meters with different seal liquid

| Serial No. | 324410 | | | 324411 | | |
Flow	K (water)	K (Oil)	Relative difference	K (water)	K (Oil)	Relative difference
0.6	8614.2	8603.7	0.12%	8620.8	8572.7	0.56%
1.2	8641.0	8611.3	0.35%	8606.9	8576.5	0.35%
3	8621.9	8600.3	0.25%	8607.4	8574.0	0.39%
4.8	8641.8	8597.8	0.51%	8612.1	8567.7	0.52%
6	8631.0	8577.1	0.63%	8610.0	8552.9	0.67%
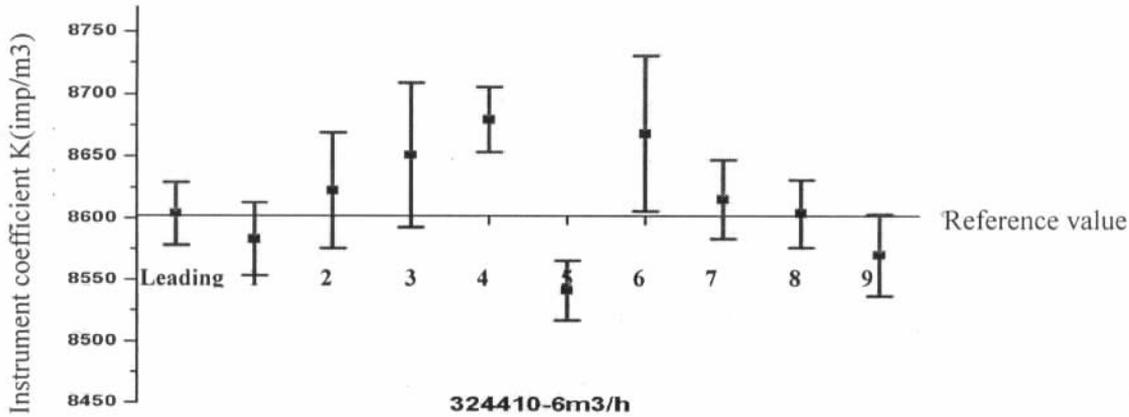
Fig.2   Intercomparison result -324410－6m^3/h
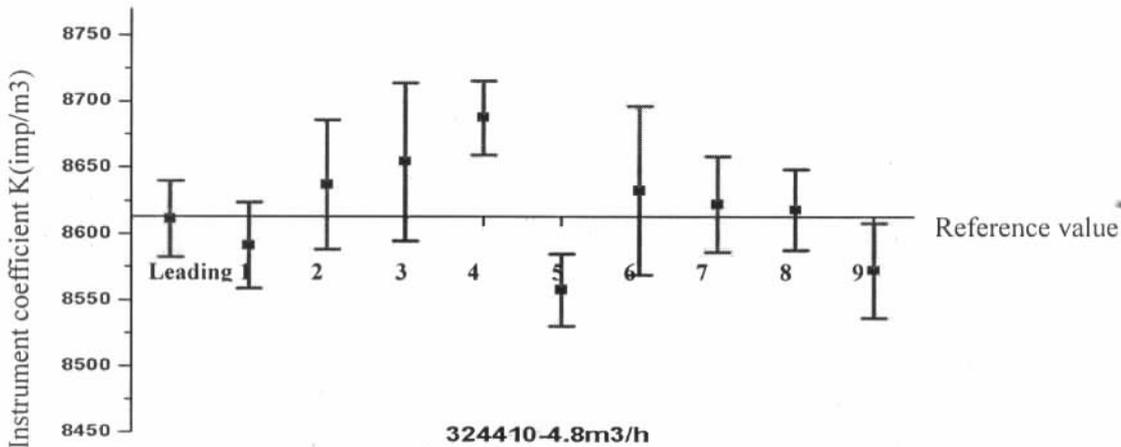
Fig.3   Intercomparison result－324410－4.8m^3/h
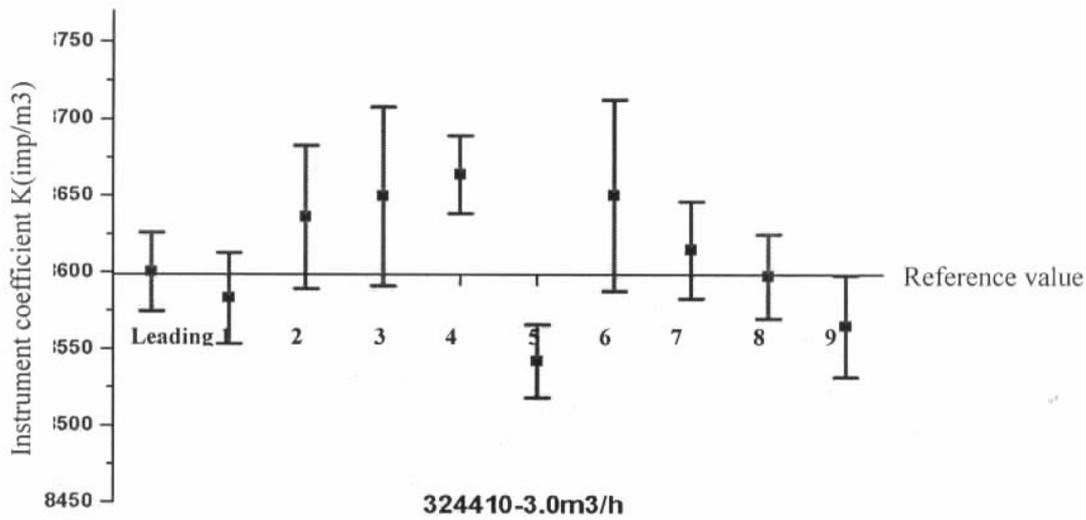
Fig. 4　　Intercomparison result－324410－3m^3/h
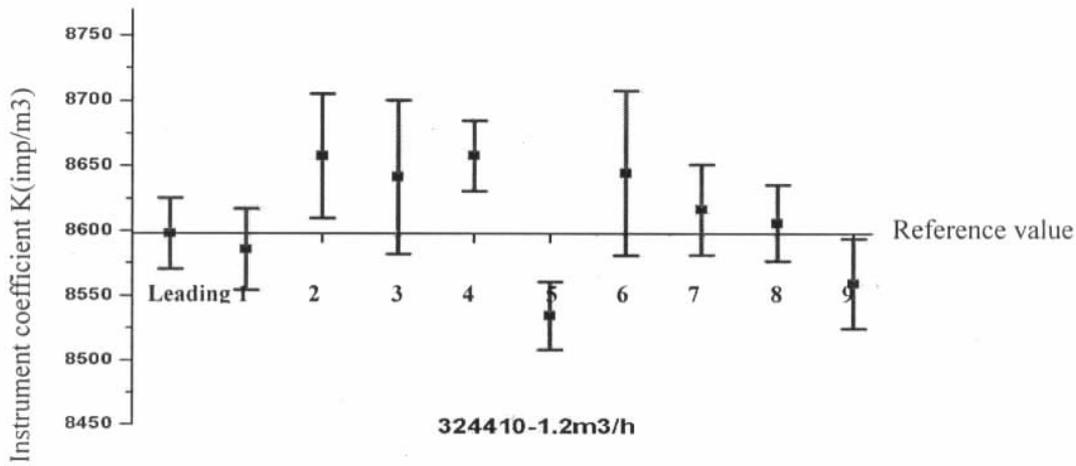
Fig.5　　Comparison results－324410－1.2m^3/h
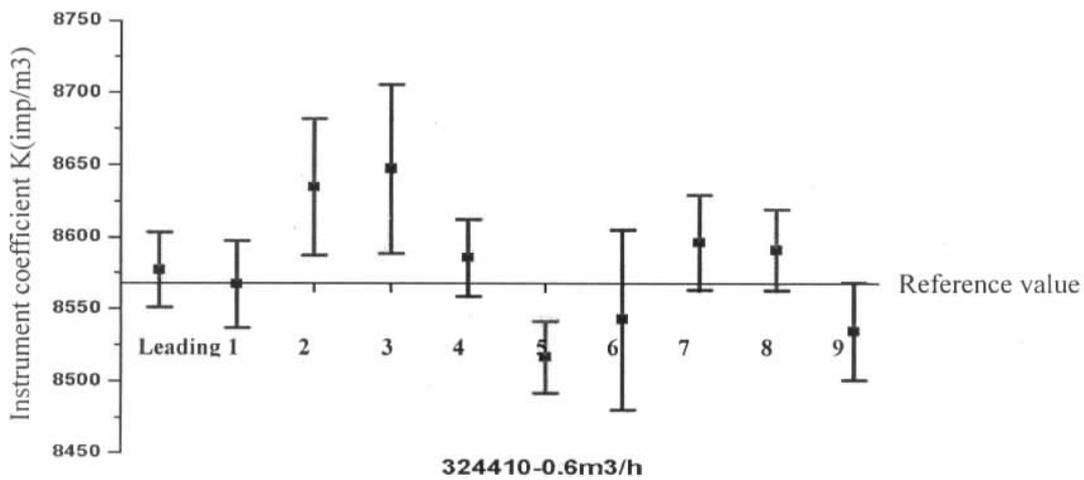
Fig. 6　　Comparison results－324410－0.6m^3/h
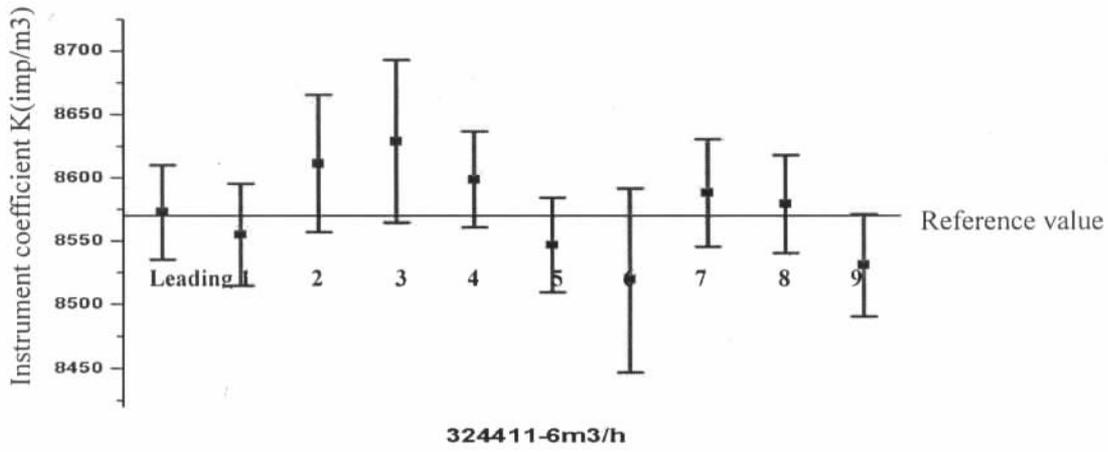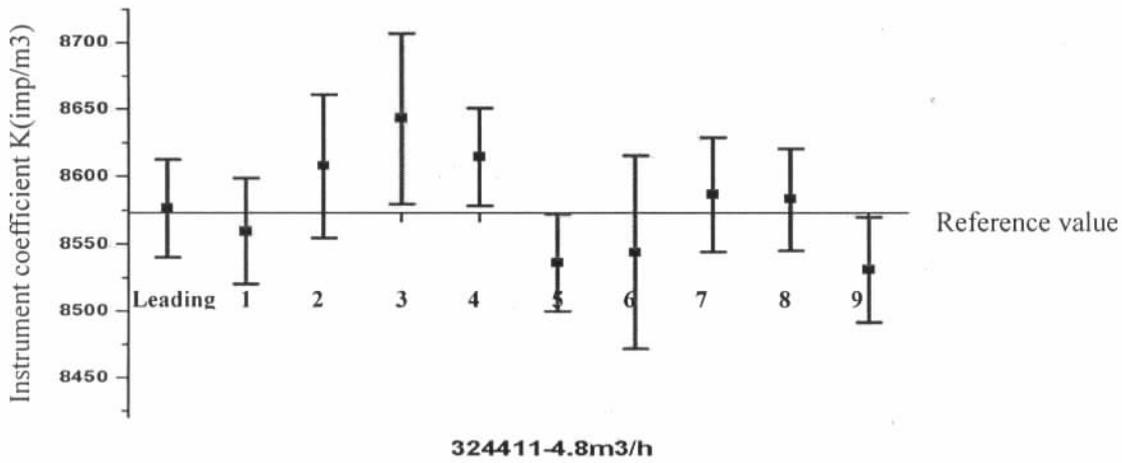
Fig 7　　Comparison results－324411－6m^3/h
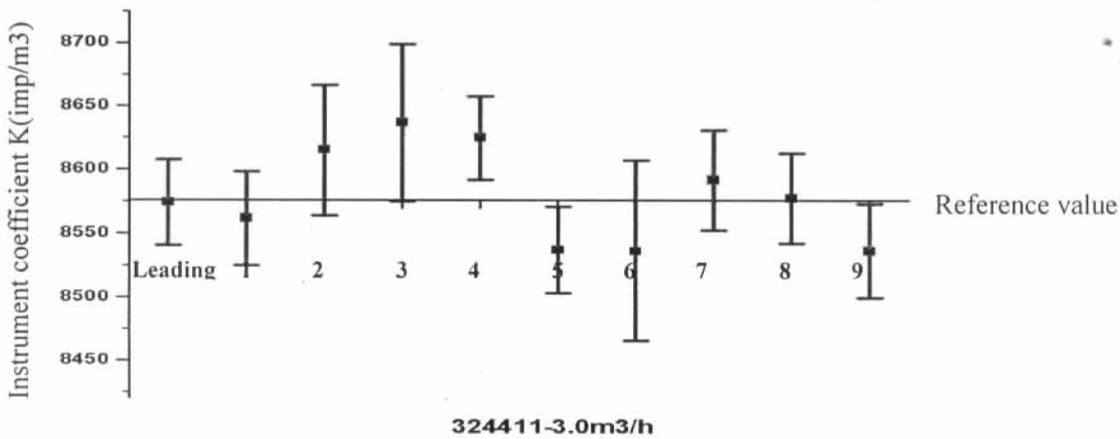

Fig. 8　　Intercomparison result－324411－4.8m^3/h

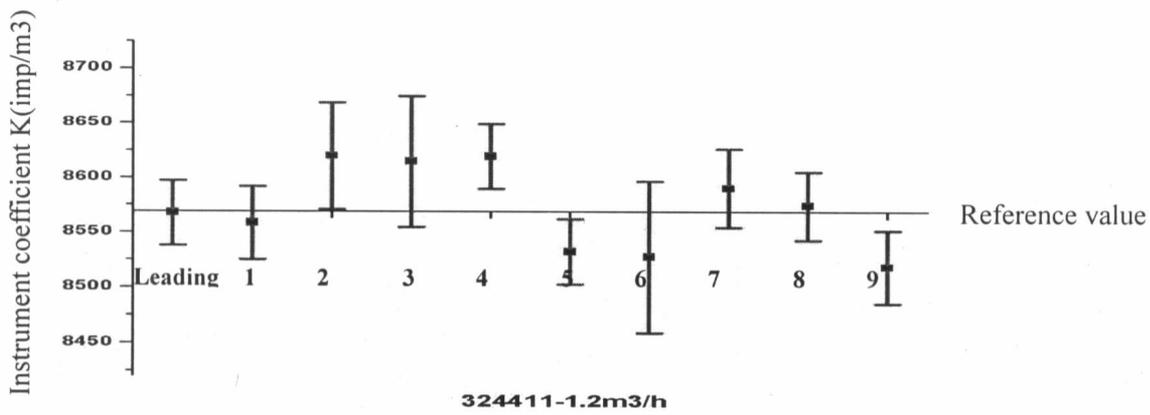Fig. 9　　Intercomparison results－324411－3m^3/h

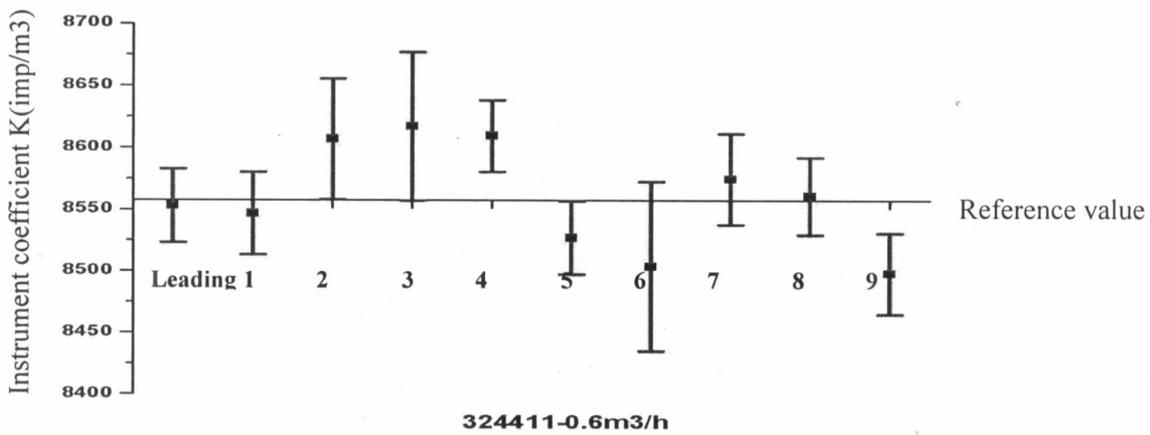Fig. 10　　Intercomparison results－324411－1.2m^3/h

Fig. 11　　　　　Intercomparison result－324411－0.6m^3/h

5. Conclusion

This intercomparison is successful, and had obtained valuable experience for further work in future. The problems occurred in the intercomparison will promote the improvement and innovation of the technology of bell provers in China.