XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

CROSS CORRELATION MASS FLOWMETER USING PULSE HEATING

T. Moriyama[1] and N. Sukemura[2]

[1] Tokushima Bunri University, Kagawa 769-2193, Japan
[2] Oval Corp., Ltd., Kanagawa 236-8645, Japan

Abstract: The aim of this study is the development of a novel nonintrusive mass flowmeter for the moved bed gravity flow of the new process, i.e.: DRI (Direct Reduction Process for Iron Ore) and the synthetic naphtha making reactor reducing the coke coal and petroleum. One of the authors already developed cross correlation method, steady state heat transfer method and PZT acoustic emission method. This paper describes a prototype of a new cross correlation method using a pulse heating marking signal based on T. Moriyama's patent application.

Keywords: cross correlation, heat transfer, pulse heating and stand pipe

1   INTRODUCTION

The aim of this study is the confirmation of the nonintrusive massflow measuring methods of stand pipe in the new process plants that are DRI (Direct Reduction Process) and the synthetic naphtha making reactor reducing the high quality coke coal and petroleum. It is required for high pressured, high temperature and corrosive feed conditions. It is very important for the distributed massflow control into the plants same as PCI (Pulverized Coal Injection system) developed by the author in [1], [16]. The process plants and the test equipment are shown in Fig. 1.
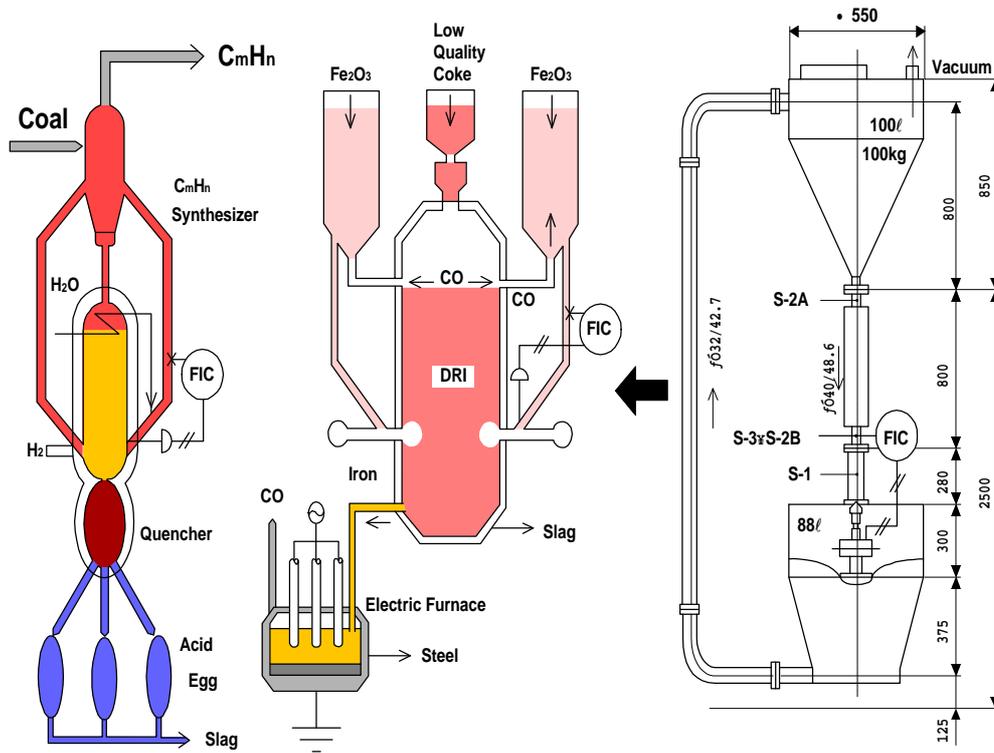

Figure 1: Process, test equipment and location S-1 3

As the working pressure is 0.45 and 1 10 MPa for PCI and the new plants, respectively, the author selected the moved bed gravity flow using the stand pipe [14]. The mass flow ratio ì of gravity flow by moved bed is as follows: cf cf [12]

$$m = \frac{r_{Sb}}{r_{gn} \times \left\{ \dfrac{r_{Sn} - r_{Sb}}{r_{Sn} - r_{gn}(P_1 + 1/P_n + 1)} \right\} \left(\dfrac{P_1 + 1}{P_n + 1} \right)}$$

XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

ñ$_{sb}$: solid bulk density [g/cm^3]

ñ$_{sn}$: solid net density [g/cm^3]

ñ$_{gn}$: gas density at normal pressure [g/cm^3]

P_1 : working pressure [10^5 Pa abs]

P_n : normal pressure [10^5 Pa abs]

Table 1: Characteristics of test feed materials

Feed material	Silica pellet	Steel
Size d_p [mm]	1.8	1.6
Weight W_p [mg]	7.6	16
Net density [g/cm^3]	2.5	7.5
Bulk density [g/cm^3]	1.5	6.0

ì will be 60 and 62 for 1 and 10 MPa against 7.5 and 0.78 of two phase flow, respectively. ì will be 2900 and 28 for 0 and 10 MPa for the following materials shown in Table 1.

The cross correlation method (S-1), the heat transfer method (S-2) and PZT AE method (S-3) are selected by the author. S-1 is studied by M.S.Beck etal [2] for the solid gas two phase flow. S-2 is studied by J.H.Laub [3] for gas or liquid flow and the author et al [4] for solid gas two phase flow. S-3 is studied by T.Horiuchi for the stand pipe [5]. S-1 3 have been studied by the author and his staff for the pipe(15.7, 20 and 40ö) feeding the same material.

2   PAST EXPERIMENTAL APPARATUS

The nonintrusive sensors S-1 S-3 and the stand pipe are shown in Fig. 1. The actual massflow rate G is measured using a weight scale and stop watches for S-1 3. The amount of the feed material is 100 kg (3 min for 2000 kg/h) per each test feed.

S-1 is a cross correlation method using Dk-13 by Endress Hauser and Iwatsu's SM-2701+SR 6310 FFT analyzer. Di is 40 mmö, The distance d of sensors A, B in Fig. 2 is 8 mm. S-2 (S-2A, S-2B) is a heat transfer method, The distance between two sensors is 700 mm and the heater is 600 mm long and below 85 V x 4.5 A. S-3 is a AE signal method using NF Circuit Inst.'s PZT (Plumbium Zirconate Titanate Zr/Ti 53/47) 900S, 922, 912, the bandpass filter, Yokogawa's 3131 DC amplifier and WX2A 1 100 ms first order lag filter and a pneumatic controller.
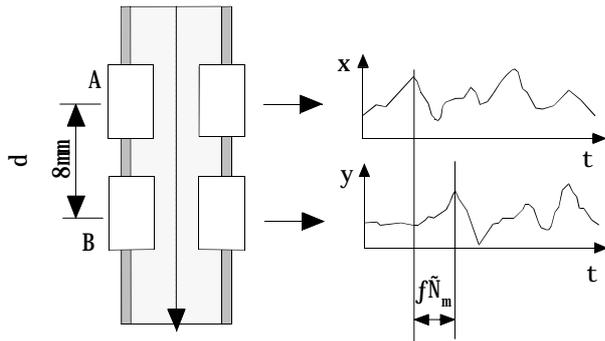
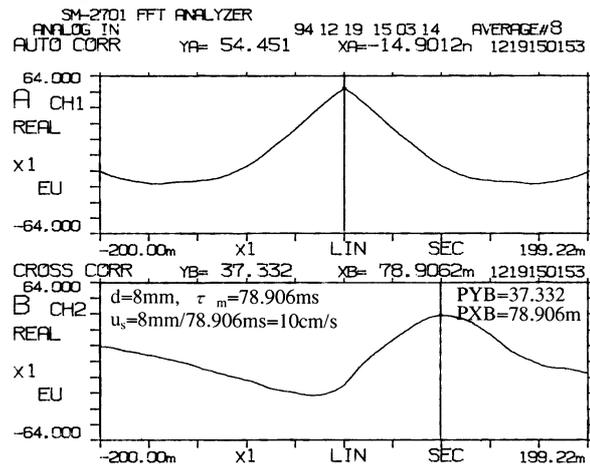Figure 2: Sensors (S-1A,S-1B) and signals (x(t),y(t))

Figure 3 Auto correlation and cross correla tion for 40ö, 5 wt% steel marker and 8 mm distance

3   EFFORTS OF EXPERIMENTS

Fig. 3 shows a sample of the cross correlation of x(t) and y(t) for 5 wt % and 40ö. " XB= " in the Figure means ô$_m$. The calculation formulas are as follows:

$$\boldsymbol{f}_{xy} = \frac{1}{T} \int_0^T x(t)\, y(t+\boldsymbol{t})\, dt$$

$$u_s = d/\boldsymbol{t}_m, \quad \boldsymbol{t} = \boldsymbol{t}_m \cdot \quad @t\cdot \quad @\frac{d\boldsymbol{f}_{xy}}{d\boldsymbol{t}} = 0$$

$$G^* = \boldsymbol{r}_{sb} A u_s \tag{1}$$

u$_s$, ô$_m$, G , u$_s$, ñ$_{sb}$ and A are solid velocity, delay time, measured massflow rate, solid velocity bulk density and solid velocity and the area of the inside of the pipe, respectively. (1) makes G from u$_s$. It is found out that the accuracy is ±2 % for full scale but the solid particles move slightly to horizontal direction in 40 ö.

Fig. 4 shows the relation between the sensor locations and the heat flow for the method. G is actual mass flow rate, T$_s$ is settling time, T is the temperature difference (T$_{c2w}$-T$_{c1w}$),

q$_h$ < 85 V x 4.5 A = 382.5 W, q$_c$ = GC$_p$T, C$_p$ = 0.326 Wh/kg K and ë$_p$ = 0.904 W/m kg K.

XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

As $q_h = GC_p(T_{c2w}-T_{c1w})$, $\varsigma = q_c/q_h > 1$. As Bi(Bio Number) = $\acute{a}d/\ddot{e}$ = 0.012, $q_{c1w} = q_{c2w} << 1\%$ of q_h, the pellets temperature is as follows:

$T_{c1} = T_{c1w}$ in wall side, $T_{c2} = T_{c2w}$ in h zone in Fig. 4. The temperature of inside the zone is equal to T_{c1w} and $q_c = \varsigma q_h = \varsigma G C_p(T_{c2w}-T_{c1w})$ in the h zone.

$\varsigma = q_c/q_h = q_{cn} = (\eth/4)Di^2/(Di^2-(Di-2h)^2)$

$h = 0.5*Di(1-(\varsigma-1)/\varsigma)^{0.5}$ is a boundary layer of heat transfer. h is equal to the thickness of a few silica pellets.

The measuring data and the calculated data are shown in the white circles of Fig. 5 and Table 2 with the data of the 15.7$\ddot{o}$ test. The accuracy is $\pm$1.4 % for full scale except the mark 1 and 2 in the Table and Figure. The black circles in the Figure are additional data at 40 .

The experimental formula is as follows:

G = 2830/T at T_{hw} = 35
= 3410/T at T_{hw} = 40 (2)

Equations (2) make measured value G for G

The accuracy = $[(G - G) / G \max] \times 100$ [%] (3)

The point 1 in Fig. 5 shows the unsteady error and the point 2 shows the error caused by heat loss .
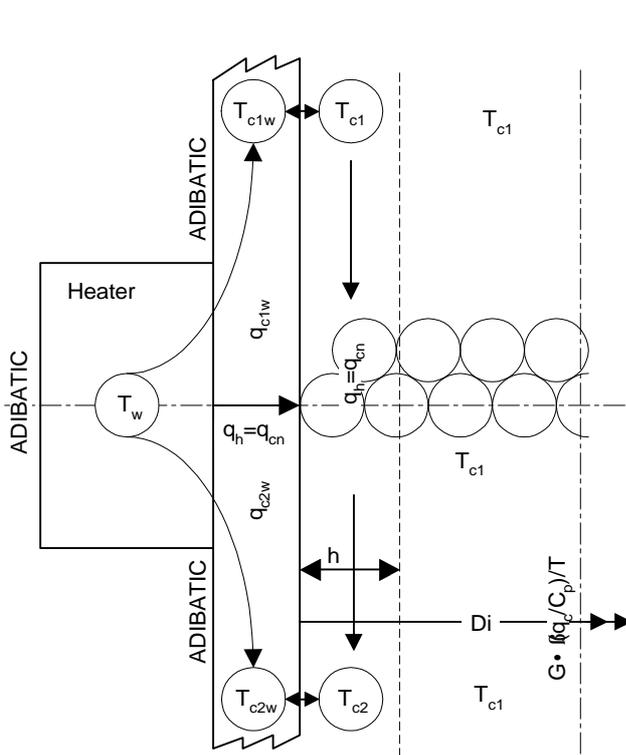

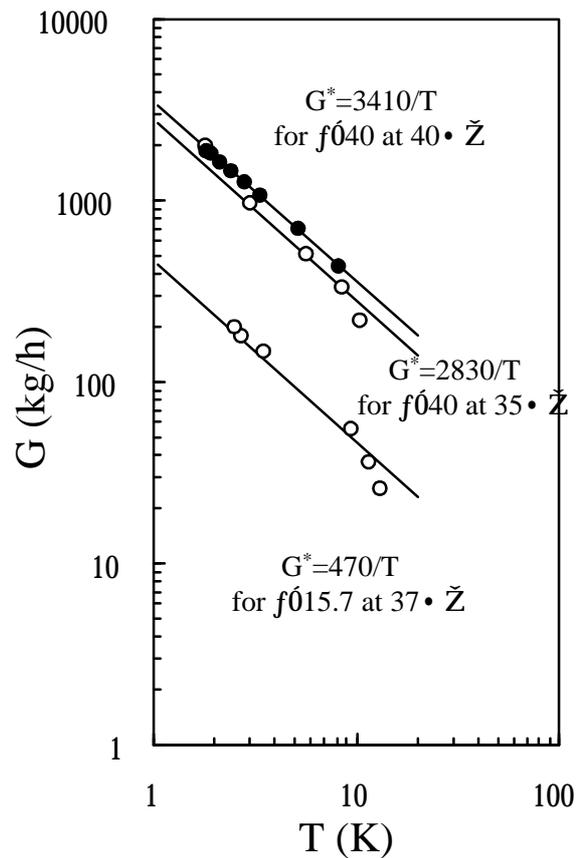Figure 4: Sensors (T = T_{c2w}-T_{c1w}) and heat flow

Figure 5: Relation between T and G based on

$T_h - T_{c1w}$ =15 K is best for the accuracy and it is $\pm$0.9 % for full scale at 40 .

The comparison table between S-1 and the others is shown in Table 3. The heat transfer method only is no calibration system for changing the size distribution of the feed material.

XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

Table 2: Data and calcuration of heat transfer method

u_s Cm/s	G kg/h	T_{hw}	q_h W	T K	T_s min	G* kg/h	(3) %
G* = 470/T for 15.7ö							
5.6	26	37	90	13.0	4.0	36	+5.0
7.7	36	38	90	11.4	3.0	41	+2.5
12	55	37	90	9.5	3.0	49	-3.0
31	147	38	90	3.5	2.0	134	-6.5
39	181	37	90	2.7	2.0	174	-3.5
43	199	37	90	2.5	2.0	188	+5.5
G* = 2830/T for 40ö							
7.4	222	35	202	10.4	18.1	272	+2.5[2]
11	334	35	270	8.4	12.0	337	+0.2
17	506	35	231	5.7	7.8	497	-0.5
32	970	35	320	3.0	4.1	943	-1.4
62	2000	35	349	1.8	1.9	1470	-21[1]
G* = 3560/T for 40ö							
14.0	438	40	168.2	8.0	7.3	445	+0.4
22.7	710	40	177.0	5.1	6.7	698	-0.9
34.4	1077	40	168.2	3.3	5.8	1079	+0.1
40.9	1278	40	168.2	2.8	5.2	1271	-0.3
46.7	1479	40	177.0	2.4	4.7	1483	+0.2
53.8	1681	40	177.0	2.1	3.7	1695	+0.7
59.8	1870	40	177.0	1.9	3.5	1873	+0.2
61.4	1920	40	180.0	1.8	3.3	1977	+3.0[1]
61.7	1929	35	180.0	1.8	3.1	1977	+2.6[1]

Table 3: Comparison table for three methods

	S-1	S-2	S-3
Dead time	1 min	0 min	0 min
Time constant	0 min	12 min	2 sec
Accuracy	2.0 %	0.9 %	1.6 %
Precision	Good	Checked	Good
Specification	+ Marker	None	+ Filter

4 NEW TEST PLANT

The aim of this test is the challenge for mose suitable measuring method [17-4] based on the above-mentioned methods. Because the cross correlation method is suitable for the marker of the feed matcrial and the steady state heat transfer method is suitable for the change of the feed specification.

The test pipe size is 44/40ö, and heat condition is a pulse heating power (80 V×4.56 A=364.8 W)×1/2 c/min (app. 0.0083 Hz). The distance between the primary sensor $è_1$ and the secondary one $è_2$ is 100 mm. The locations of the sensors are shown in Fig. 8.

5 EFFORTS OF THE NEW TEST

The primary temperature $è_1$ is 74.8 47.4   and secondary temperature $è_2$ is 38.0 33.8   . The calculation formula is based on Equation (1). x(t) is $è_1$. y(t) is $è_2$. The cross correlation function is $ö_{12}$ between $è_1$ and $è_2$. d is the distance

between $è_1$ and $è_2$. u_{st} is the value concerned with u_s. For $ô_m$ based on $\dfrac{d\boldsymbol{f}_{12}}{dt} = 0$, $u_{st} = d\Big/ \boldsymbol{t}_m$.

The relation between u_{st} and u_s^* is $u_s^* = 10^{0.39} u_{st}^{1.58}$ (4)   based on the Least Root Meen Square method and shown in Fig. 8 and Table 4. u_s^* means the value on Equation (4). Fig. 9 and Table 4 include the data of the past cross correlation method using steel marker. Fig. 8 is a sample of $ö_{12}$.
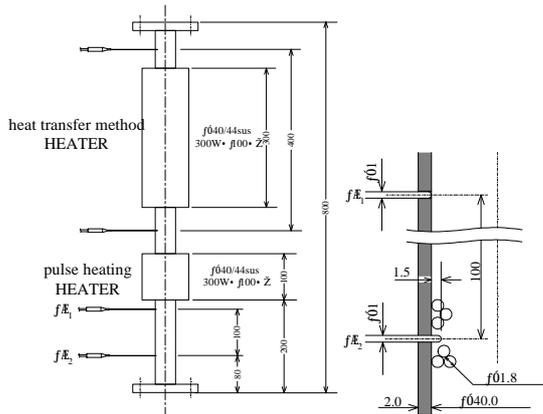
XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

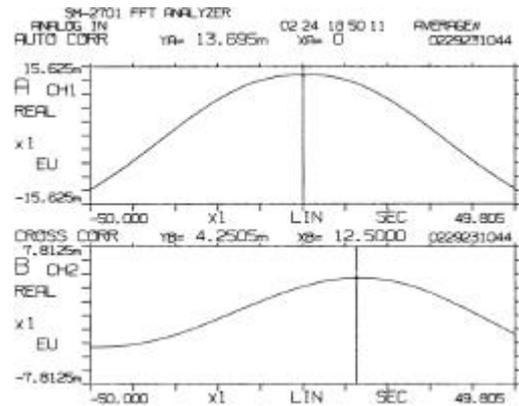Figure 6: Test equipment and location $\grave{e}_1$ and $\grave{e}_2$

Figure 8: Auto correlation and cross correlation for 40ö, cross correlation method using pulse heating
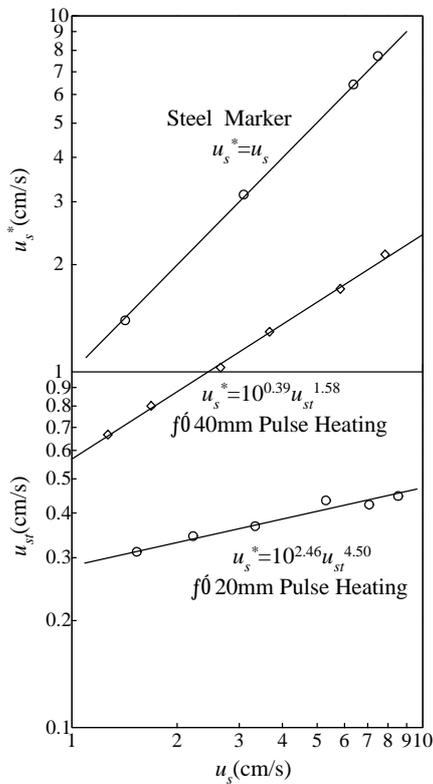

Figure 7 Relation between u_s and u_{st}

Table 4: Relation between u_s and u_{st}

G kg/h	$\grave{e}_{1\,max}$	$\grave{E}_{2\,max}$	q_h W	u_s cm/s	u_{st} cm/s	u_s^* cm/s	Error %
83.25	72.1	49.5	364.8	1.270	0.665	1.29	0.24
110.51	70.3	51.0	364.8	1.686	0.8	1.73	0.54
173.63	61.3	46.6	364.8	2.649	1.024	2.55	-1.22
240.80	54.2	41.5	364.8	3.673	1.296	3.70	0.33
382.98	48.4	38.5	364.8	5.842	1.707	5.71	-1.63
513.67	44.2	35.9	364.8	7.835	2.133	8.12	3.51

6   FUTURE STUDY

The relation between the accuracy and the first 1 cycle sampling data should be checked.

ACKNOWLEDGEMENTS

REFERENCES

[1] Y. Shinozaki, T. Iwamura and H. Marushima (Kawasaki Steel Corp.), T. Moriyama, S. Fujii and K. Achiba, 'Pulverized coal injection system into blast furnace- KDP-I, Proc. PNEUMATECH-I, May 1982, pp. 1-22

[2] M. S. Beck,J. Drane,A. Plaskowski and N. Wainwright, Particle velocity and mass flow measurement in pneumatic Conveyors, J. Powder Technology, 1968/69, p.269-277

[3] J. H. Laub, The Boundary-layer mass flowmeter, J.Instrument & Control Systems, Vol 34, 1957, p. 642- 643

[4] T. Moriyama, S. Fujii, K. Abe and K. Kobayashi, Mass flowmeter using heat transfer for dense phase solid gas two phase flow, Fluid Control amd Measurement Vol.2, PERGAMON, 1985, p.795-800 Referred by Yong Yan, Massflow measurement of bulk solid in pneumatic pipelines, Meas. Sci. Technol. 7 1996, p. 1687-1706

[5] T. Horiuchi, Noise flow meter, IMEKO-V, 1970

[6] T. Moriyama, Cross correlation method for gravity flow, Proc. The Society of Instrument and Control Engineers, Japan, July 1991, p. 943-946

[7] T. Moriyama, Novel massflow measurement methods for gravity flow in stand pipe, Proc. IMEKO TC-7 AIMaC'91, Sept. 1991, p. 365-368

[8] T. Moriyama, Evaluation uzing FFT analyzer on cross correlation method for mass flow measurement of stand pipe, Proc. SICE, Jury, 1992, p. 1034-1042

[9] T. Moriyama. Mass flow measurement using heat transfer method for stand pipe, Proc. SICE, Jury,1992, p. 1063-1066

[10] T. Moriyama and O. Sato, Mass flow measurement using PZT acoustic emission sensor for stand pipe, Proc. SICE, July 1994, p. 739-741

[11] T. Moriyama and S. Tachibana, Mass flow measurement using heat transfer method for moved bed gravity flow (in Japanese), Trans. SICE, Vol. 31, No. 6, 1995, p. 722-727

[12] T. Moriyama, Study on Mass Flow Measurement and Control for Dense Phase Flow of Gas Solid Mixture (in Japanese), Doctor Thesis, Waseda Univ., Dec.,1986

[13] T. Moriyama, Nonintrusive measuring methods on massflow rate for moved bed gravity flow in the new plants, IMTC/96, June 1996, p. 671-674

[14] T. Moriyama, Massflow measurement using heat transfer for moved bed gravity flow of the process, FLOMEKO'96, Oct. 1996, p. 220-225

[15] T. Moriyama, Massflow meter for stand pipe, XIV IMEKO'97, June 1-6, 1997

[16] T. Moriyama, Pulse Heating Mass Flowmeter for Moved Bed Gravity Flow, Patent Application, Hei-9-191970

[17] T. Moriyama, A novel mass flowmeter for moved bed gravity flow, FLUCOME'97, Sept. 1-3, 1997, p. 47-52

[18] T. Moriyama and N. Sukemura, Cross correlation mass flowmeter using pulse heating method, FLOMEKO'98, June 15-17, 1998, p. 337-342

[19] T. Moriyama and M. Kondo, Simulation for heat transfer flowmeter of moved bed gravity flow, FLOMEKO'98, June 15-17, 1998, p. 393-398

AUTHOR: Takashi MORIYAMA, Professor, Dr. Eng., Head of Department of Mechanical Electronic Engineering, Faculty of Engineering, Tokushima Bunri University, Kagawa 769-2193, Japan, Phone:81- (0) 87-894-5111 ex 3401, Fax:+81- (0) 87-894-4201, E-mail: moriyama@me.bunri-u.ac.jp, Norio SUKEMURA, department of RD, Oval Corp. Ltd., Kanagawa 236-8645, Japan, Phone:81-(0)45-785-7243, Fax:+81-(0)45-781-9920, E-mail: rd_1@yk.oval.co.jp, http://www.bunri-u.ac.jp/eng/moriyama/MORIYAMA.htm