WORLD CLASS IN FLUID ENGINEERING

CR 8047

Sulzer Compax Static Mixer Performance Testing -A reduced report

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Prepared for:

Sulzer Chemtech Limited

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Executive Summary

Sulzer Chemtech required independent assessment of its CompaX1 mixer in terms of the mixer quality (coefficient of variation) and pressure drop. BHR Group Limited carried out pressure and CoV measurements using the LIF technique with a 106 mm diameter mixer for flow ratios ranging from 10 to 10000. The work suggests that at each flow-rate ratio, CoV is roughly constant in the turbulent flow regime. The average CoV for Re>20000 varies from 0.033 to 0.045 for flow ratio 10 to 10000.

The pressure drop measurements at various bulk flow rates shows that the mean system loss coefficient for Re> 20000 is 2.63.

1 The Sulzer CompaX mixer is a proprietary Sulzer Chemtech product protected by several patents and pending patents in various countries. CompaX is a trademark of Sulzer Chemtech registered in various countries.

NOMENCLATURE

Symbol	Meaning	Units
α	Flow ratio	-
C_{avg}	average measured concentration of additive	ppb
c_i	concentration at *i*th probe position or	ppb
		i^{th} pixel location
CoV	coefficient of variation	-
D	main pipe or channel	m
D_H	hydraulic diameter	m
F_D	Darcy friction factor	-
g	acceleration due to gravity	ms^{-2}
Δh	head-loss	m
L	length	m
L_m	length of static mixer between leading edge of first element and trailing edge of last element	m
n	number of pixel locations or	-
Δp	pressure drop	$N.m^{-2}$
q	additive flow rate	mls^{-1}
Q	bulk flow-rate	ls^{-1}
U	velocity of bulk flow	ms^{-1}
ρ	density	kgm^{-3}
µ	dynamic viscosity	Pa.s

Dimensionless Groups

K, System Loss Coefficient:

$$K = \frac{\Delta H_{mixer}}{U^2 / 2g}$$

Reynolds number, *Re*

$$\mathrm{Re} = \frac{\rho u D}{\mu}$$

Contents

1. Introduction/Background

Sulzer Chemtech requires independent mixture quality (CoV) and pressure drop measurements for its CompaX static mixer design. BHR Group has extensive experience in measuring static mixer performance using Laser Induced Fluorescence (LIF) to non-intrusively evaluate mixture quality (CoV) and pressure drop. This report describes the work carried out at BHR to evaluate and report on the Sulzer CompaX performance over a range of operating conditions. As agreed with Sulzer, mixture quality measurements have been made at a distance 5L/D downstream of the mixer.

2. Objectives

To measure Sulzer CompaX mixture quality (CoV) and pressure drop using BHR Group's LIF test rig over a range of Reynolds numbers and flowrate ratios.

3. Method and Work Details.

3.1 Model/Rig

A clear Perspex test section of 106mm internal diameter was fabricated to enable the downstream flange of the CompaX mixer to be positioned 5L/D upstream of the LIF measurement plane. As shown in figure 3.1, the CompaX mixer is flanged to the main test section. The mixer was installed such that different diameter dosing inserts for each flow ratios could be fitted without removal of the mixer. A Perspex viewing box surrounds the test section where the measurements are made. The gap between the viewing box and the test section is filled with distilled water to avoid optical distortions due to the curved surface of the test section while viewing from the camera. One side of the viewing box is designed such that the surface is perpendicular to the axis of the camera lens to minimise distortion.

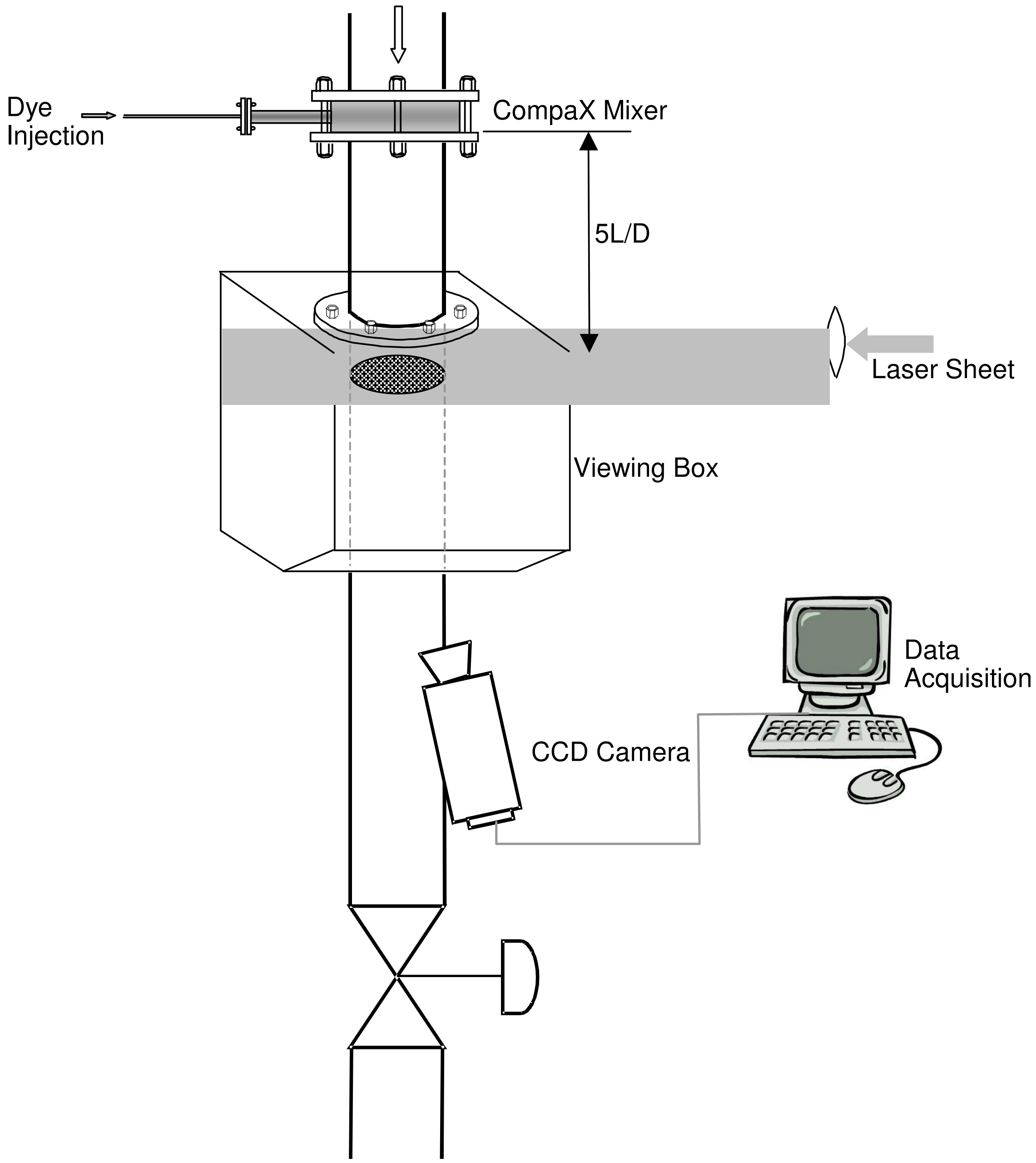

Figure 3.1: Test rig set up

3.2 LIF Technique

LIF is a non-intrusive technique which enables the concentration distribution (and hence mixture quality) across the whole pipe cross-section to be measured very accurately. A fluorescent dye is dosed into the mixer and the resultant dispersion passes through a sheet of laser light positioned downstream of the mixer. As the dye passes through the laser sheet it fluoresces and the resultant image is captured using a CCD camera. For each CoV measurement, a total of 150 images were taken over a 7.5 second period, where each image consisted of 200,000 pixels. Each image is analysed and the fluorescence intensity (which is proportional to tracer concentration) measured for each pixel. This results in a highly accurate series of CoV measurements and a digital record of the mixture quality at a specified distance downstream of the mixer.

The CoV was calculated using the following equation:

$$CoV = \left[\frac{\sum_{i=1}^{n} (c_i - c_{avg})^2}{n} \right]^{0.5} \frac{1}{c_{avg}} \qquad (1)$$

Where:

c_i = time averaged pixel value (ppb)

c_{avg} = c_i averaged for all pixels (ppb)

n = total number of pixel locations (-)

To calculate CoV, the concentrations were time averaged for each pixel. The concentration of the dye tracer was different for the different additive ratios used. The aim was to achieve a target concentration of 3ppb. Rhodamine WT was used as an additive fluid. Calibration images were obtained for dye concentrations of 2, 3 and 4ppb. Using these calibration images with the fluorescence intensity images, the actual dye concentration is obtained.

3.3 Head-loss Measurement

Head-loss was measured using a water manometer. The manometer was connected across two pressure tappings, 5D upstream and 10D downstream of the mixer and the head-loss measured as the difference in water level between the two arms. To calculate the pressure drop only due to the mixer, the pressure drop in the 15D length of the straight pipe was subtracted from the total pressure loss measured from the manometers.

3.4 Test matrix

Work reported here consists 4 flow ratios (Q/q = 10, 100, 1000 and 10000). The diameter of the dosing inserts was chosen as below (ref. email from Andreas Neher, 5th Mar 2008).

Q/q	**Insert Diameter, mm**
10	22
100	7
1000	3
10000	3

Dye injection was made using a syringe pump for low flow rates, a gear pump and a mono positive displacement pump for higher flow rates. All the flow rates were measured using a calibrated digital flow-meter and a set of rotameters.

The flow rates required to achieve the above flow ratios over a Re range of approximately 20000 to 100000 are tabulated in the Appendix A1. The tables show flow rates, velocity and Re in the injection, main pipe and the total flow.

3.5 Results/Discussion

3.5.1 System loss coefficient, K

A system loss coefficient is defined as the non-dimensional difference in total pressure between the extreme ends of two long straight pipes or passages when there is a zero-loss component between the two pipes or passages and when the real component is installed.

Table 1 shows Pressure drop across the mixer at different flow rates and Reynolds numbers.

Flow-rate l/s	Velocity m s-1	Re_{Pipe} -	ΔH (Total) mm	ΔH (Pipe) mm	ΔH (Mixer) mm	Loss Coefficient
2	0.227	23975	7.5	0.788	6.712	2.56
3	0.34	35963	17	1.768	15.232	2.59
4	0.453	47951	32	3.138	28.862	2.76
5	0.567	59938	49	4.916	44.084	2.69
6	0.68	71926	70	7.070	62.930	2.67
7	0.793	83914	94	9.615	84.385	2.63
8	0.907	95901	119	12.579	106.421	2.54

Table 1 – Head-loss Measurement and system loss coefficient

The pressure drop measured across the manometer is shown as ΔH (Total) which includes pressure drop due to the mixer and the 15D length of the straight pipe. The pressure in the straight pipe was calculated as:

$$\Delta H = \frac{fLU^2}{2gD} \qquad (3)$$

Where

f is the friction factor, used as 0.02 for a given pipe and flow conditions (Miller, 1990)

L is the straight pipe length, which is equal to 15D

It can be noticed that the pressure drop due to the pipe is approximately 7 to 10% of the total pressure drop.

The system loss coefficient was calculated using the mixer pressure drop as per the following equation

$$K = \frac{\Delta H_{mixer}}{U^2 / 2g} \qquad (2)$$

Where:

K	=	System loss coefficient	
ΔH_{mixer}		Head loss due to mixer	m
U		fluid velocity	m s^{-1}
g		Gravitational acceleration	m s^{-2}

The same information is plotted in Figure 3.2. As can be noticed, the system loss coefficient is almost constant for all Re suggesting fully turbulent condition. The mean K for Re>20000 is 2.63.

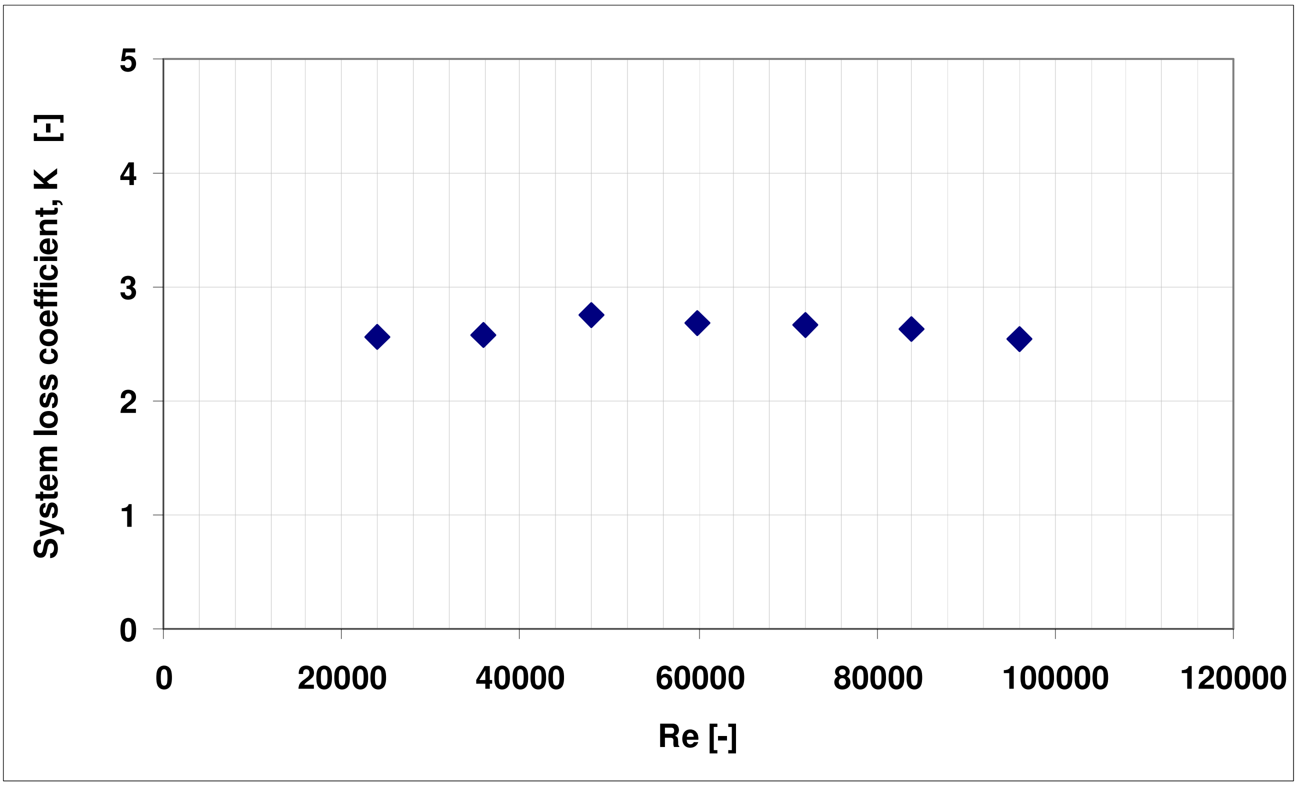

Figure 3.2 – Friction Factor vs Reynolds Number

3.5.2 Coefficient of Variation (CoV)

Sulzer Chemtech Limited measured CoV using gas probes at a range of locations in the pipe cross section, corresponding locations in the present work are shown in Figure 3.3. The CoV results shown here were calculated using the concentration values at these locations. Each point represents approximately 3mm square.

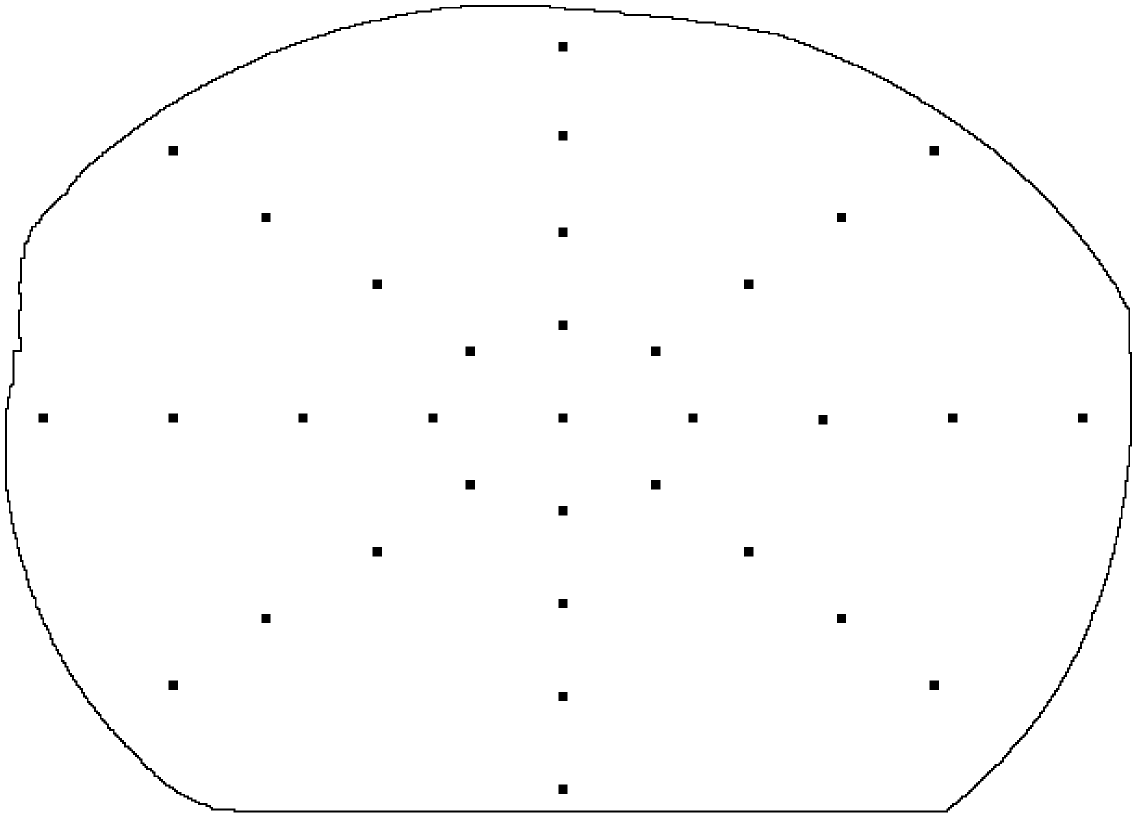

Figure 3.3: CoV vs Bulk Reynolds Number

Table 2 shows the coefficient of variation obtained at different flow ratios and bulk flow rates.

	A10000		A1000		A100		A10	
l/s	Re	CoV	Re	CoV	Re	CoV	Re	CoV
2.0	24026	0.023	24047	0.034	24264	0.039	26426	0.054
3.0	36039	0.034	36071	0.038	36395	0.040	39639	0.037
4.0	48052	0.035	48095	0.034	48527	0.034	52851	0.043
5.0	60064	0.030	60119	0.032	60659	0.034	66064	0.047
6.0	72077	0.039	72142	0.035	72791	0.033	79277	0.044
7.0	84090	0.028	84166	0.031	84923	0.029	92490	0.044
8.0	96103	0.040	96190	0.029	97054	0.033	105703	0.049

Table 2 – CoV vs Downstream Reynolds Number

Figure 3.4 shows the graphical representation of Table 2.

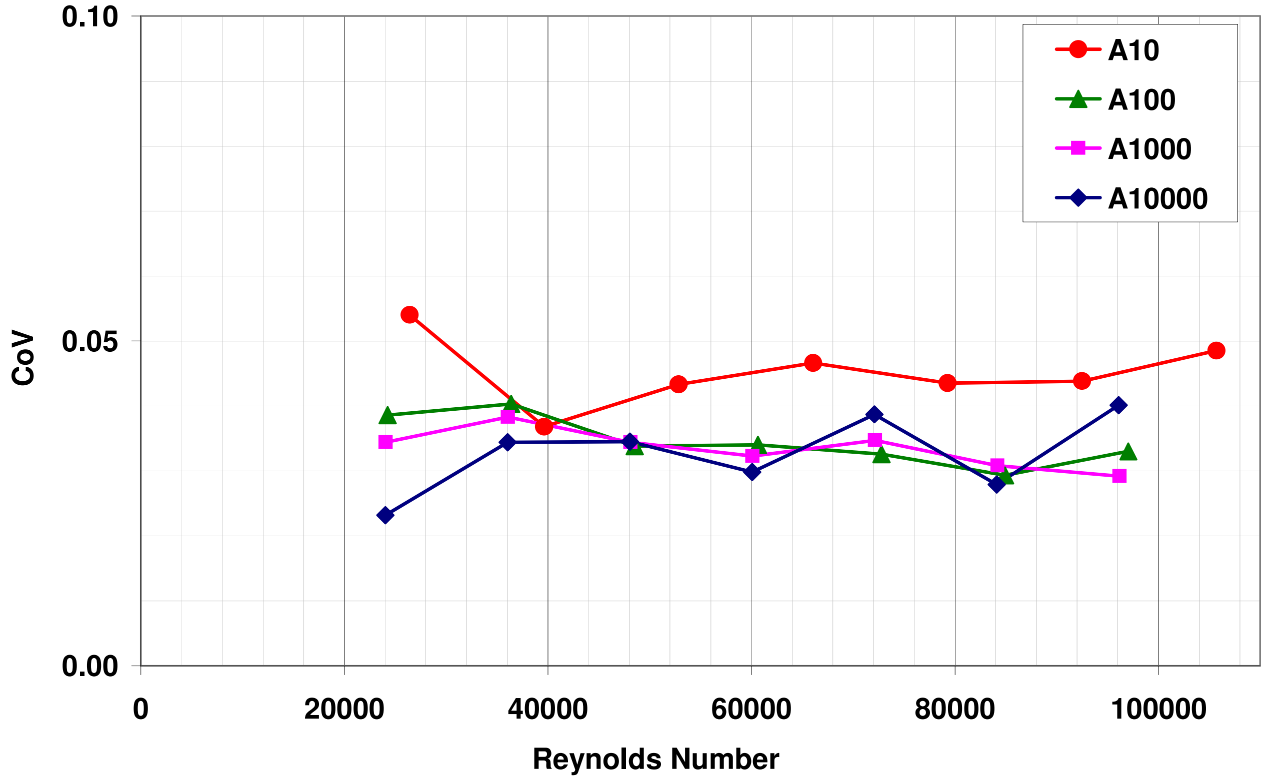

Figure 3.4: CoV vs Bulk Reynolds Number

The results from the tests on the CompaX mixer show that at each flow-rate ratio (α=10 to 10000), CoV became roughly constant in the turbulent flow regime Re > 20000. The average CoV for Re>20000 varied from 0.033 to 0.045 for α=10 to 10000.

4. Conclusions

The LIF technique has been used to investigate the performance of Sulzer CompaX mixer in a 106 mm diameter pipe. The work suggests that for flow-rate ratio from 10 to 10000, CoV is always below 0.05 in the turbulent flow regime Re > 20,000.

The pressure drop measurements at various bulk flow rates shows that the mean system loss coefficient for Re> 20000 is K = 2.63.

5. References

Miller D.S. (1990), “Internal flow systems”, BHR Group Limited

A1. Flow rates at different alpha and Reynolds number

ALPHA 10000

Injection			Main		Total		
Flow (ml/min)	Velocity (m/s)	Re	Flow (l/s)	Velocity (m/s)	Flow (l/s)	Velocity (m/s)	RePipe -
12.0	0.028	85	2.0	0.227	2.00	0.227	24026
18.0	0.042	127	3.0	0.340	3.00	0.340	36039
24.0	0.057	170	4.0	0.453	4.00	0.453	48052
30.0	0.071	212	5.0	0.567	5.00	0.567	60064
36.0	0.085	255	6.0	0.680	6.00	0.680	72077
42.0	0.099	297	7.0	0.793	7.00	0.793	84090
48.0	0.113	340	8.0	0.907	8.00	0.907	96103

ALPHA 1000

Injection			Main		Total		
Flow (ml/min)	Velocity (m/s)	Re	Flow (l/s)	Velocity (m/s)	Flow (l/s)	Velocity (m/s)	RePipe -
120	0.28	849	2.00	0.227	2.00	0.227	24047
180	0.42	1273	3.00	0.340	3.00	0.340	36071
240	0.57	1698	4.00	0.453	4.00	0.454	48095
300	0.71	2122	5.00	0.567	5.01	0.567	60119
360	0.85	2546	6.00	0.680	6.01	0.681	72142
420	0.99	2971	7.00	0.793	7.01	0.794	84166
480	1.13	3395	8.00	0.907	8.01	0.907	96190

ALPHA 100

Injection			Main		Total		
Flow (l/min)	Velocity (m/s)	Re	Flow (l/s)	Velocity (m/s)	Flow (l/s)	Velocity (m/s)	RePipe -
1.20	0.52	3638	2.00	0.227	2.02	0.229	24264
1.80	0.78	5457	3.00	0.340	3.03	0.343	36395
2.40	1.04	7276	4.00	0.453	4.04	0.458	48527
3.00	1.30	9095	5.00	0.567	5.05	0.572	60659
3.60	1.56	10913	6.00	0.680	6.06	0.687	72791
4.20	1.82	12732	7.00	0.793	7.07	0.801	84923
4.80	2.08	14551	8.00	0.907	8.08	0.916	97054

ALPHA 10

Injection			Main		Total		
Flow (l/min)	Velocity (m/s)	Re	Flow (l/s)	Velocity (m/s)	Flow (l/s)	Velocity (m/s)	RePipe -
12.0	0.53	11575	2.00	0.227	2.20	0.249	26426
18.0	0.79	17362	3.00	0.340	3.30	0.374	39639
24.0	1.05	23150	4.00	0.453	4.40	0.499	52851
30.0	1.32	28937	5.00	0.567	5.50	0.623	66064
36.0	1.58	34725	6.00	0.680	6.60	0.748	79277
42.0	1.84	40512	7.00	0.793	7.70	0.873	92490
48.0	2.10	46300	8.00	0.907	8.80	0.997	105703

Report Control Sheet

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Sulzer Compax Static Mixer Performance Testing
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