CHAPTER 5 RESULTS AND EVALUATION OF CFD ANALYSIS

5.1 RESULTS OF CFD ANALYSIS

It should be noted in the presentation of these results that the overall pressure differences are given for the shafts being considered. These pressure differences are calculated for the particular shaft length and are, therefore, difficult to compare with each other. Thus a value of pressure loss per m of shaft is also included to allow for this comparison.

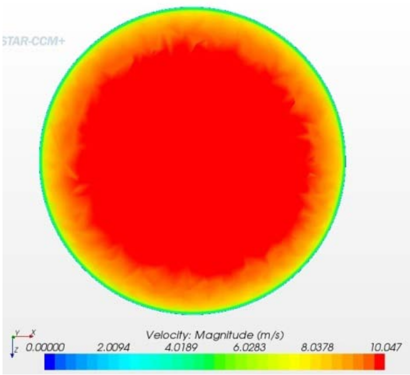
5.1.1 CFD Simulation No. 1 (Shaft Barrel)

The shaft asperity for this simulation was modelled as being 10 mm. This value was based on observations in the shaft and was used for the evaluation of all the CFD models except the 12N shaft. A value of 20 mm was used for the 12N shaft. The results of the simulations for all the shafts under consideration are shown in Table 5-1.

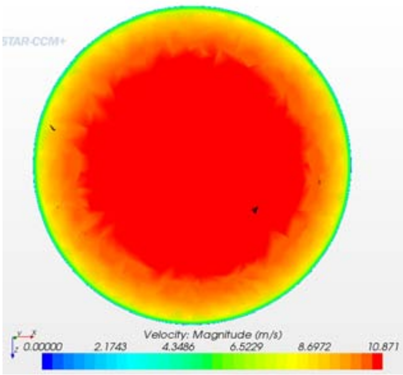
Table 5-1: CFD simulation No. T01 – Shaft barrel pressure losses

	14 Shaft	11 Shaft	1 Shaft	11c Shaft	12N Shaft
Total calculated pressure loss over shaft length (Pa)	123.4	117.9	44.1	212.9	266.0
Calculated pressure loss (per m) (Pa/m)	0.14	0.19	0.09	0.18	0.30
Calculated shaft Chezy-Darcy friction factor (f)	0.021	0.022	0.021	0.023	0.028
Total calculated pressure loss over shaft length (CFD) (Pa)	65.8	56.8	23.0	103.6	89.5
Measured pressure loss (per m) (CFD) (Pa/m)	0.08	0.09	0.05	0.09	0.10
Resultant Chezy-Darcy friction factor from CFD data (f)	0.011	0.011	0.011	0.011	0.010
Reynolds number (Re)	3 923 672	3 290 971	3 245 682	2 977 968	3 770 693
% Difference	47%	52%	48%	51%	55%

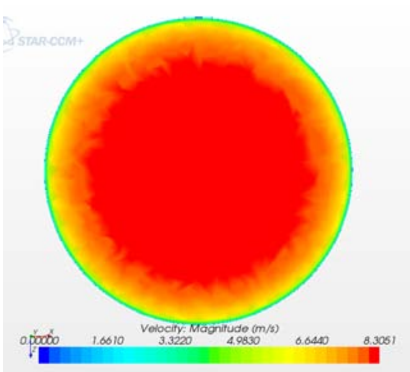
This comparison shows that there are significant differences between the CFD results and the calculated results. This is in part attributed to the large relative roughness of the shaft as well as the high Reynolds number. In addition, the formula used for the calculation of the Chezy-Darcy friction factor does take into account that there is an accuracy of plus or minus 15% on the values for the Moody chart (White, 1986). This cumulative inaccuracy should be taken into consideration.



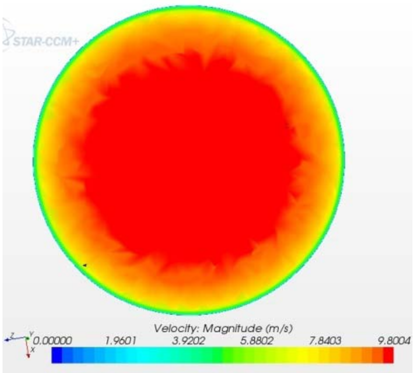
14 Shaft



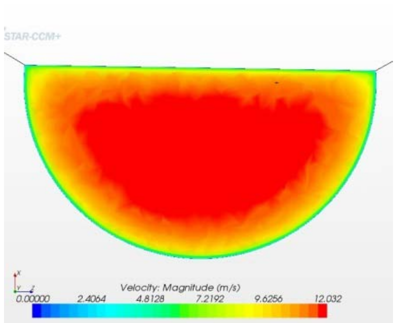
11 Shaft



1 Shaft



11C Shaft



12N Shaft

Figure 5-1: Velocity profiles for simulation T01 – Shaft barrel pressure losses

The shaft cross-sections showing the velocity profiles for the various shafts are shown in Figure 5-1. There is nothing untoward in these profiles, but they should be borne in mind as a basis of comparison when viewing subsequent cross-sections.

5.1.2 CFD Simulations Nos T02, T03 and T04 (T02 – Shaft barrel and 1 bunton across the shaft; T03 – Shaft barrel and 2 buntons across the shaft; T04 – Shaft barrel and full bunton set)

It is appropriate that these simulations be discussed together as they all seek to provide a better understanding of the behaviour of ventilation flow around the buntons in the shaft. The results of these simulations are given in Table 5-2.

Table 5-2: CFD simulations Nos T02, T03 and T04

(T02 – Shaft barrel and 1 bunton across the shaft; T03 – Shaft barrel and 2 buntons across the shaft; T04 – Shaft barrel and full bunton set)

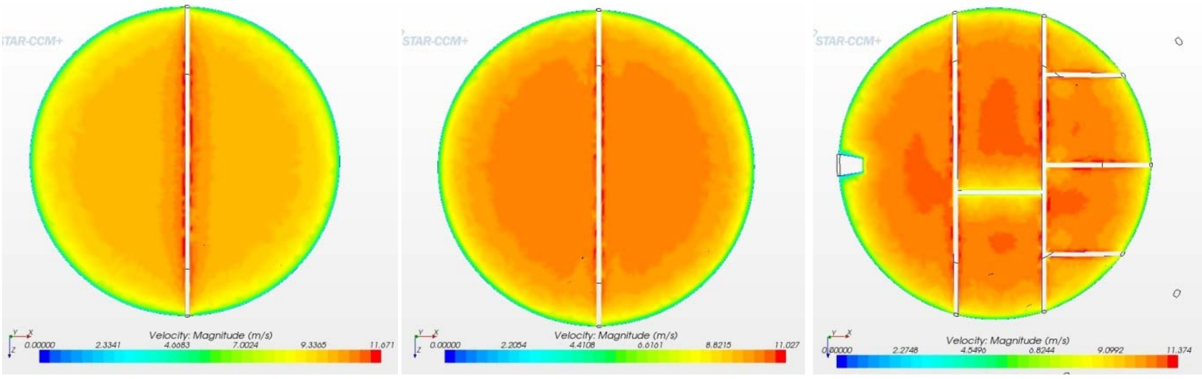
	14 Shaft	**11 Shaft**	**1 Shaft**	**11C Shaft**	**12N Shaft**
Simulation No. T02 – Shaft barrel and 1 bunton across the shaft					
Total calculated pressure loss over shaft length (Pa)	174.6	165.1	65.6	296.6	-
Calculated pressure loss (per m) (Pa/m)	0.20	0.27	0.13	0.26	-
Drag coefficient (assumed) (C_D)	1.30	1.30	1.55	1.30	-
Total calculated pressure loss over shaft length (CFD) (Pa)	93.4	97.9	37.4	177.6	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.11	0.16	0.07	0.15	-
Drag coefficient (CFD) (C_D)	0.90	1.47	1.33	1.49	-
% Difference	47%	41%	43%	40%	-

	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T03 – Shaft barrel and 2 buntons across the shaft					
Total calculated pressure loss over shaft length (Pa)	246.8	386.8	175.9	479.6	-
Calculated pressure loss (per m) (Pa/m)	0.28	0.62	0.35	0.42	-
Drag coefficient (assumed) (C_D)	1.30	1.30	1.55	1.30	-
Total calculated pressure loss over shaft length (CFD) (Pa)	135.4	136.0	51.0	245.1	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.16	0.22	0.10	0.21	-
Drag coefficient (CFD) (C_D)	0.74	0.49	0.33	0.70	-
% Difference	45%	65%	71%	49%	-
Simulation No. T04 – Shaft barrel and full bunton set					
Total calculated pressure loss over shaft length (Pa)	564.9	540.8	259.6	671.5	
Calculated pressure loss (per m) (Pa/m)	0.65	0.87	0.52	0.58	-
Drag coefficient (assumed) (C_D)	1.39	1.37	1.55	1.30	-
Total calculated pressure loss over shaft length (CFD) (Pa)	382.3	337.0	139.3	425.3	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.44	0.54	0.28	0.37	-
Drag coefficient (CFD) (C_D)	1.01	0.92	0.84	0.93	-
% Difference	32%	38%	46%	37%	-

The following should be noted when reviewing the data in Table 5–2.

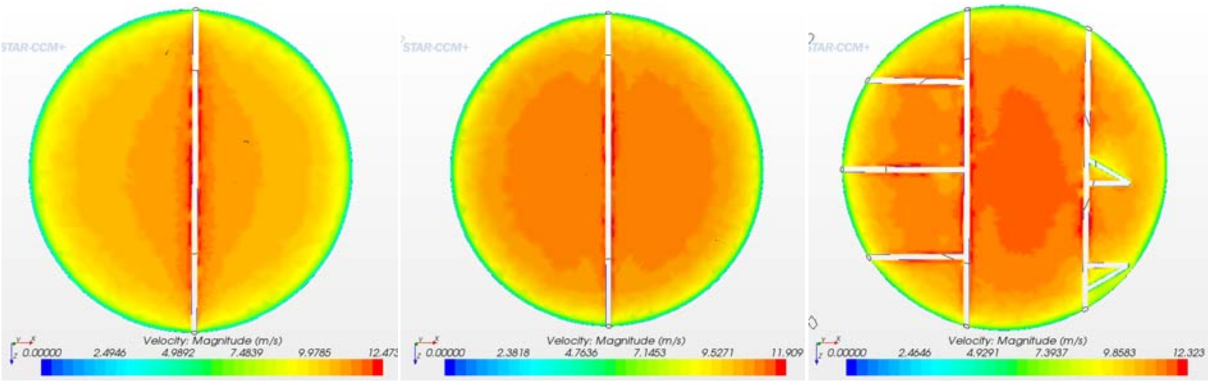
i The drag coefficients from the CFD results were calculated after the pressure losses from the shaft barrel calculated in simulation T01 had been subtracted. The remaining pressure loss was assumed to be directly attributable to the buntons.

ii All the data were corrected for the density differences that were obtained from the test results in the shaft.



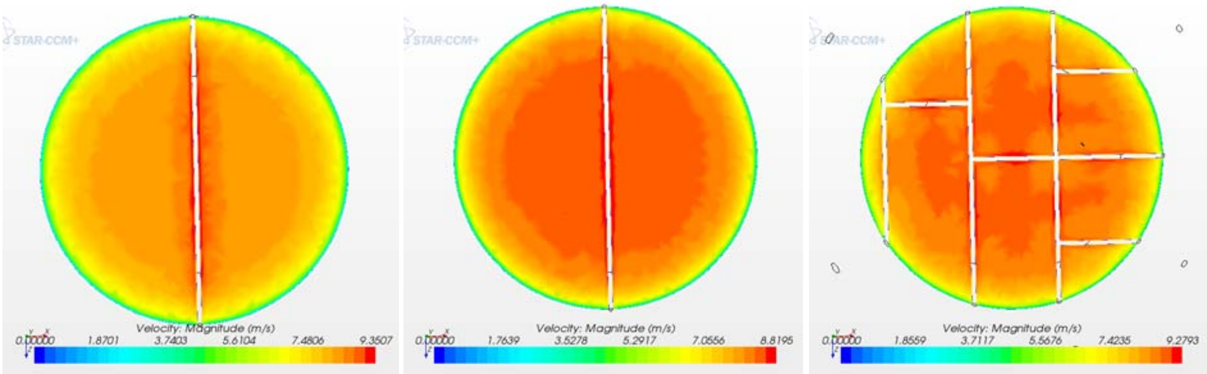
1 Bunton **2 Buntons in Series** **Complete Bunton Set**

14 Shaft



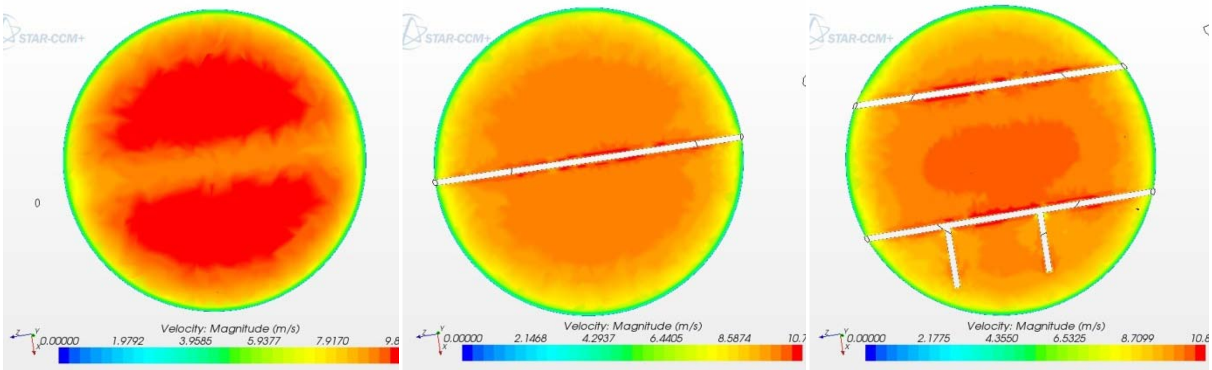
1 Bunton **2 Buntons in Series** **Complete Bunton Set**

11 Shaft



1 Bunton | **2 Buntons in Series** | **Complete Bunton Set**

1 Shaft



1 Bunton | **2 Buntons in Series** | **Complete Bunton Set**

11C Shaft

No Buntons in 12N Shaft

Figure 5-2: Velocity profiles for simulations T02, T03 and T04

(T02 – Shaft barrel and 1 bunton across the shaft; T03 – Shaft barrel and 2 buntons across the shaft; T04 – Shaft barrel and full bunton set)

The shaft cross-sections showing the velocity profiles for the various shafts are shown in Figure 5-2. What is interesting to note from these profiles is the comparative increase in the velocities as the additional buntons are added. This is most apparent when the increase in the velocity for the central portion of the shaft for simulation T04 is noted. It should be noted the areas of maximum velocity are also the areas where conveyances will travel.

5.1.3 CFD Simulation Nos T05, T06 and T07

(T05 – Shaft barrel and pipes at pipe diameter; T06 – Shaft barrel and pipes at flange diameter; T07 – Shaft barrel and pipes including flanges)

It is appropriate that these simulations be discussed together as they all seek to provide a better understanding of the behaviour of ventilation flow around the pipes in the shaft. The results of these simulations are given in Table 5-3.

Table 5-3: CFD simulations Nos 5, 6 and 7

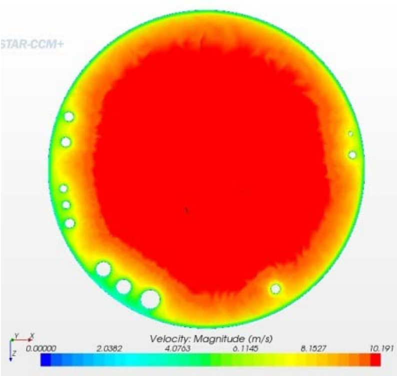
(T05 – Shaft barrel and pipes at pipe diameter; T06 – Shaft barrel and pipes at flange diameter; T07 – Shaft barrel and pipes including flanges)

	14 Shaft	**11 Shaft**	**1 Shaft**	**11C Shaft**	**12N Shaft**
Simulation No. T05 – Shaft barrel and pipes at pipe diameter					
Total calculated pressure loss over shaft length (Pa)	125.4	173.5	44.7	-	265.7
Calculated pressure loss (per m) (Pa/m)	0.14	0.28	0.09	-	0.30
Calculated pressure loss over shaft length due to piping (Pa)	0.4	54.0	0.1	-	0.0
Total calculated pressure loss over shaft length (CFD) (Pa)	62.0	61.5	23.2	-	89.0
Measured pressure loss (per m) (CFD) (Pa/m)	0.07	0.10	0.05	-	0.10
Pressure loss over shaft length due to piping (CFD) (Pa)	-3.8	4.8	0.3	-	-0.5
% Difference	51%	65%	48%	-	67%

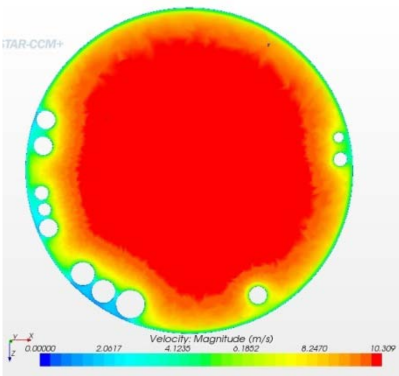
	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T06 – Shaft barrel and pipes at flange diameter					
Total calculated pressure loss over shaft length (Pa)	130.0	181.0	45.9	-	266.0
Calculated pressure loss (per m) (Pa/m)	0.15	0.29	0.09	-	0.30
Calculated pressure loss over shaft length due to piping (Pa)	1.4	58.1	0.4	-	0.0
Total calculated pressure loss over shaft length (CFD) (Pa)	63.9	64.8	23.2	-	93.9
Measured pressure loss (per m) (CFD) (Pa/m)	0.07	0.10	0.05	-	0.11
Pressure loss over shaft length due to piping (CFD) (Pa)	-1.9	8.1	0.3	-	4.4
% Difference	51%	64%	49%	-	67%
Simulation No. T07 – Shaft barrel and pipes including flanges					
Total calculated pressure loss over shaft length (Pa)	123.0	181.0	45.9	-	266.0
Calculated pressure loss (per m) (Pa/m)	0.15	0.29	0.09	-	0.30
Calculated pressure loss over shaft length due to piping (Pa)	1.4	58.1	0.4	-	0.0
Total calculated pressure loss over shaft length (CFD) (Pa)	95.8	79.9	28.3	-	107.7
Measured pressure loss (per m)	0.11	0.13	0.06	-	0.12

	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
(CFD) (Pa/m)					
Pressure loss over shaft length due to piping (CFD) (Pa)	30.0	23.2	5.3	-	18.2
% Difference	26%	56%	38%	-	67%

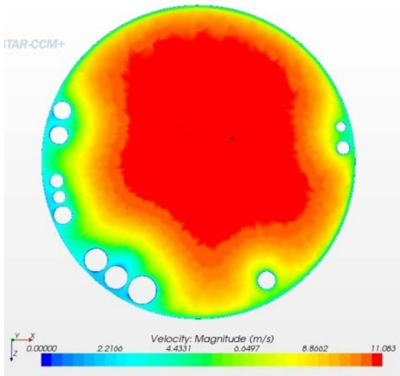
A number of interesting differences from the current theory for the calculation of the pressure drops resulting from the pipes in a shaft are apparent in the above data. There are, once again, significant differences between the pressure drops calculated from the theory and those from the CFD calculations.



Pipes at Pipe Diameter

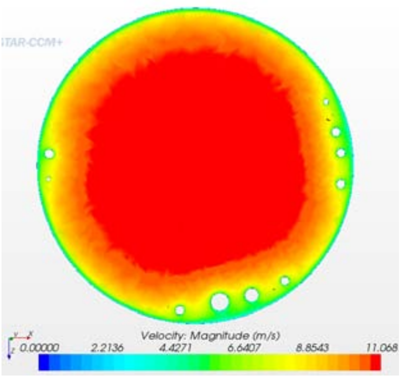


Pipes at Flange Diameter

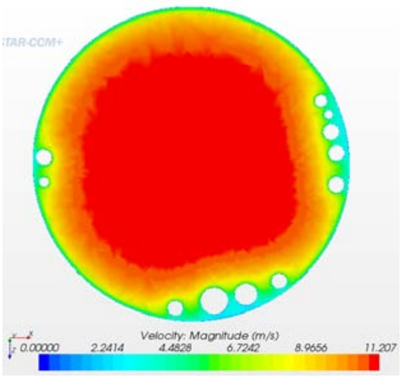


Pipes including Flanges

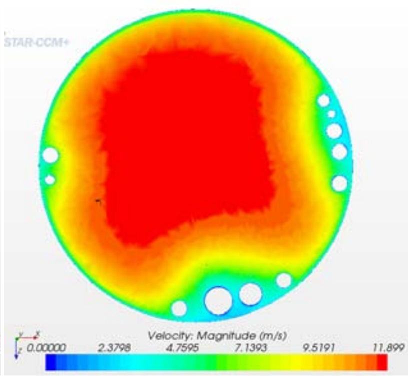
14 Shaft



Pipes at Pipe Diameter

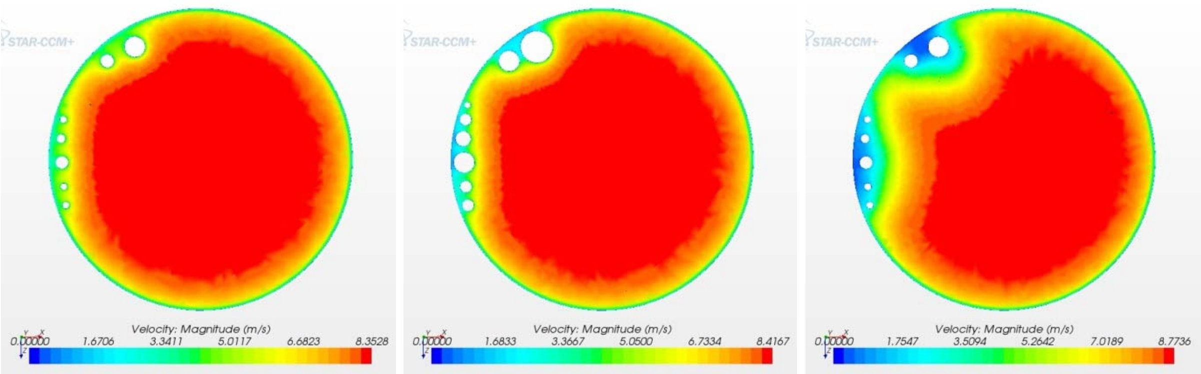


Pipes at Flange Diameter



Pipes including Flanges

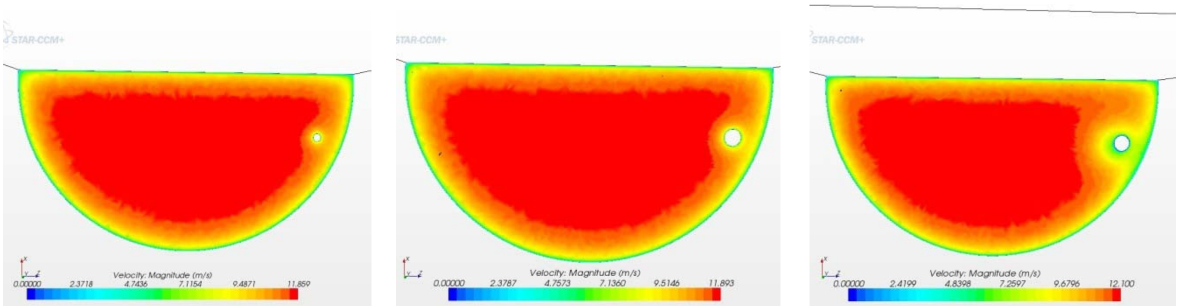
11 Shaft



Pipes at Pipe Diameter **Pipes at Flange Diameter** **Pipes including Flanges**

1 Shaft

No Pipes in Section of 11C Shaft



Pipes at Pipe Diameter **Pipes at Flange Diameter** **Pipes including Flanges**

12N Shaft

Figure 5-3: Velocity profiles for simulations 5, 6 and 7

(T05 – Shaft barrel and pipes at pipe diameter; T06 – Shaft barrel and pipes at flange diameter; T07 – Shaft barrel and pipes including flanges)

The shaft cross-sections showing the velocity profiles for the various shafts are shown in Figure 5-3. It can be seen that the inclusion of the pipes (T05), even at flange diameter (T06), has significantly less effect on the flow of the ventilation air through the shaft than the inclusion of the pipes with the flanges (T07). This effect is not accounted for in the current theory.

5.1.4 CFD Simulations Nos T08, T09 and T10

(T08 – Shaft barrel and buntons and pipes at pipe diameter; T09 – Shaft barrel and buntons and pipes at flange diameter; T10 – Shaft barrel and buntons and pipes including flanges)

It is appropriate that these simulations be discussed together as they all seek to provide a better understanding of the behaviour of ventilation flow around the pipes in the shaft in conjunction with the buntons. The results of these simulations are given in Table 5-4.

Table 5-4: CFD simulations Nos 8, 9 and 10

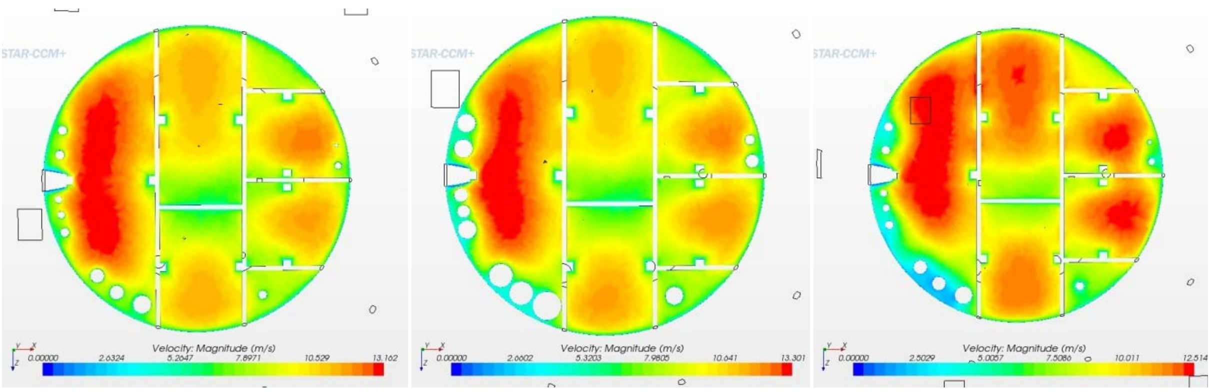
(T08 – Shaft barrel and buntons and pipes at pipe diameter; T09 – Shaft barrel and buntons and pipes at flange diameter; T10 - Shaft barrel and buntons and pipes including flanges)

	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T08 – Shaft barrel, and buntons and pipes at pipe diameter					
Total calculated pressure loss over shaft length (Pa)	579.5	552.0	265.0	-	-
Calculated pressure loss (per m) (Pa/m)	0.67	0.89	0.53	-	-
Total calculated pressure loss over shaft length (CFD) (Pa)	538.1	479.1	210.0	-	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.62	0.77	0.42	-	-
Unaccounted pressure losses (Pa)	159.7	137.2	70.4	-	-
% Difference	7%	13%	21%	-	-

	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T09 – Shaft barrel and buntons and pipes at flange diameter					
Total calculated pressure loss over shaft length (Pa)	612.5	583.9	276.1	-	-
Calculated pressure loss (per m) (Pa/m)	0.71	0.94	0.55	-	-
Total calculated pressure loss over shaft length (CFD) (Pa)	552.0	499.3	209.7	-	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.64	0.81	0.42	-	-
Unaccounted pressure losses (Pa)	171.6	154.3	70.2	-	-
% Difference	10%	14%	24%	-	-
Simulation No. 10 – Shaft barrel and buntons and pipes including flanges					
Total calculated pressure loss over shaft length (Pa)	612.5	584.0	276.1	-	-
Calculated pressure loss (per m) (Pa/m)	0.71	0.94	0.55	-	-
Total calculated pressure loss over shaft length (CFD) (Pa)	615.3	537.0	209.2	-	-
Measured pressure loss (per m) (CFD) (Pa/m)	0.71	0.87	0.42	-	-
Unaccounted pressure losses (Pa)	203.0	176.9	64.6	-	-
% Difference	0%	8%	24%	-	-

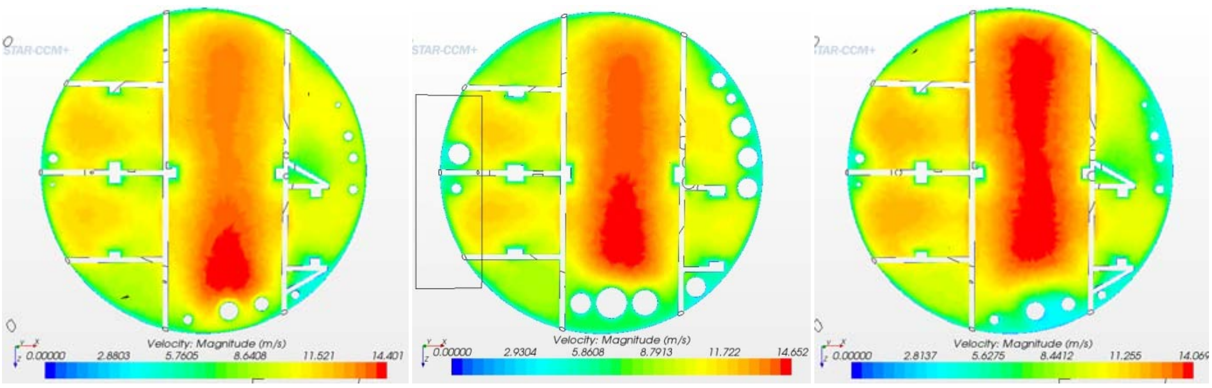
The overall correlation between the calculated data and those taken from the CFD simulations in these tests was much closer than in any of the previous tests. The differences between the theory and the simulation results were between 3 and 23%. This decrease in the differences was not anticipated.

It is interesting to note that the increase in pressure from the CFD simulations was a direct result of the piping in the shaft being modelled in conjunction with the buntons. This combination resulted in additional pressure losses which were not predicted by the theory.



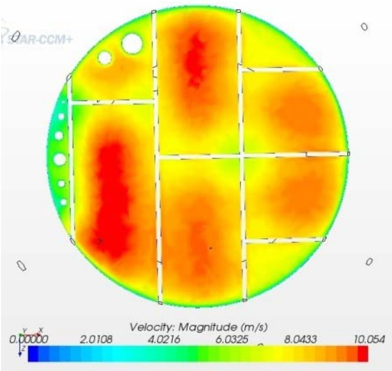
Full Bunton Set, Pipes at Pipe Diameter | **Full Bunton Set, Pipes at Flange Diameter** | **Full Bunton Set, Pipes including Flanges**

14 Shaft

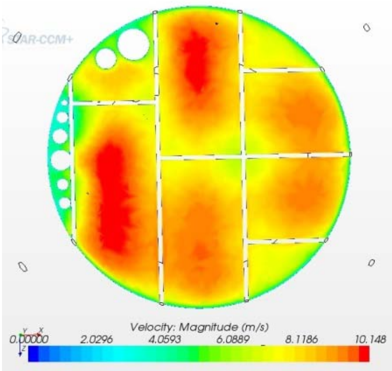


Full Bunton Set, Pipes at Pipe Diameter | **Full Bunton Set, Pipes at Flange Diameter** | **Full Bunton Set, Pipes including Flanges**

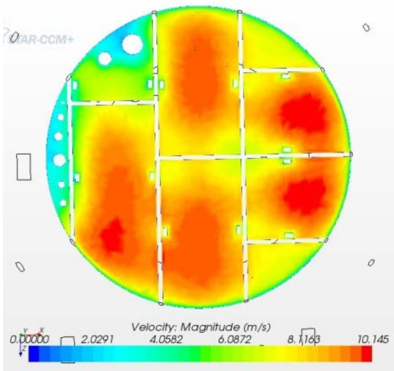
11 Shaft



Full Bunton Set, Pipes at Pipe Diameter

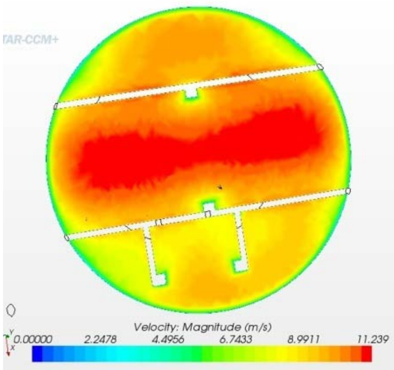


Full Bunton Set, Pipes at Flange Diameter



Full Bunton Set, Pipes including Flanges

1 Shaft



Full Bunton Set, No Pipes

No Pipes in Section of 11C Shaft

No Buntons in 12N Shaft

Figure 5-4: Velocity profiles for simulations 8, 9 and 10

(T08 – Shaft barrel and buntons and pipes at pipe diameter; T09 – Shaft barrel and buntons and pipes at flange diameter; T10 – Shaft barrel and buntons and pipes including flanges)

In the velocity plots of the cross-sections of the various shafts shown in Figure 5-4, a number of interesting facts are apparent.

In the 14 shaft test, the small connection between the two main buntons is a square section. The area of reduced velocity around this section is significantly larger than that for the more aerodynamic sections. The free-velocity section of the shafts also decreases more for the piping with flanges than for the piping without them. This is consistent with the observations from simulations T05, T06 and T07.

5.1.5 CFD Simulations Nos T11, T12, T13, T14 and T15 (T11 – Shaft barrel and buntons and pipes including flanges and skip 1; T12 – Shaft barrel and buntons and pipes including flanges and skip 2; T13 – Shaft barrel and buntons and pipes including flanges and man cage 1; T14 – Shaft barrel and buntons and pipes including flanges and man cage 2; T15 – Shaft barrel and buntons and pipes including flanges and service cage)

It is appropriate that these simulations be discussed together as they all seek to provide a better understanding of the behaviour of ventilation flow around the conveyances when they are assumed to have been stopped in the shaft. The results of these simulations are given in Table 5-5.

Table 5-5: CFD simulations Nos 11, 12, 13, 14 and 15 T15

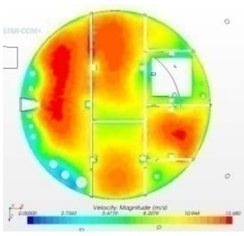
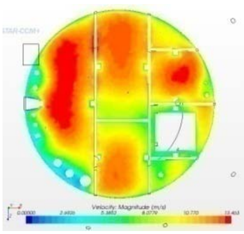
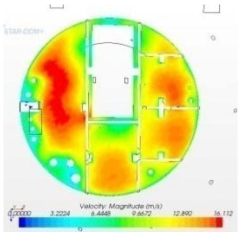
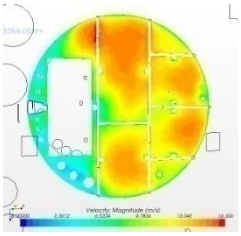
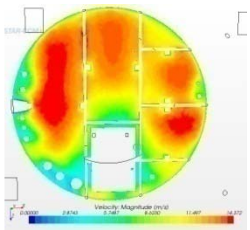
(T11 – Shaft barrel and buntons and pipes including flanges and skip 1; T12 – Shaft barrel and buntons and pipes including flanges and skip 2; T13 – Shaft barrel and buntons and pipes including flanges and man cage 1; T14 – Shaft barrel and buntons and pipes including flanges and man cage 2; T15 – Shaft barrel and buntons and pipes including flanges and service cage)

	14 Shaft	**11 Shaft**	**1 Shaft**	**11C Shaft**	**12N Shaft**
Simulation No. T11 – Shaft barrel and buntons and pipes including flanges and skip 1					
Pressure loss calculated from theory	706.1	638.2	310.0	-	332.0
Calculated pressure loss (per m) (Pa/m)	0.81	1.03	0.61	-	0.38
Pressure loss calculated from CFD (Pa)	618.7	541.0	211.1	-	112.8
Measured pressure loss (per m) (CFD) (Pa/m)	1.02	1.50	0.81	-	0.68
Unaccounted pressure losses (Pa)	206.5	180.8	66.5	-	-84.5
% Difference	12%	15%	32%	-	72%

	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T12 – Shaft barrel and buntons and pipes including flanges and skip 2					
Total calculated pressure loss over shaft length (Pa)	706.1	638.2	310.0	-	377.0
Calculated pressure loss (per m) (Pa/m)	0.81	1.03	0.61	-	0.43
Total calculated pressure loss over shaft length (CFD) (Pa)	618.6	541.1	211.6	-	112.8
Measured pressure loss (per m) (CFD) (Pa/m)	1.00	1.53	0.80	-	0.57
Unaccounted pressure losses (Pa)	206.3	180.9	66.9	-	-84.4
% Difference	12%	15%	32%	-	75%
Simulation No. T13 – Shaft barrel and buntons and pipes including flanges and man cage 1					
Total calculated pressure loss over shaft length (Pa)	649.5	630.6	285.1	713.8	-
Calculated pressure loss (per m) (Pa/m)	0.75	1.02	0.57	0.62	-
Total calculated pressure loss over Shaft Length (CFD) (Pa)	631.2	568.0	215.0	444.8	-
Measured pressure loss (per m) (CFD) (Pa/m)	2.06	4.79	1.30	3.62	-
Unaccounted pressure losses (Pa)	218.9	207.8	70.4	19.5	-
% Difference	3%	10%	25%	38%	-

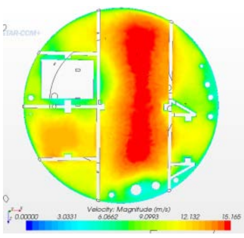
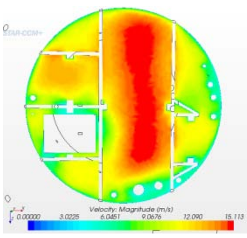
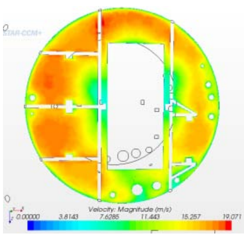
	14 Shaft	11 Shaft	1 Shaft	11C Shaft	12N Shaft
Simulation No. T14 – Shaft barrel and buntons and pipes including flanges and man cage 2					
Total calculated pressure loss over shaft length (Pa)	649.5	-	285.1	-	-
Calculated pressure loss (per m) (Pa/m)	0.75	-	0.57	-	-
Total calculated pressure loss over shaft length (CFD) (Pa)	634.6	-	215.9	-	-
Measured pressure loss (per m) (CFD) (Pa/m)	2.35	-	1.43	-	-
Unaccounted pressure losses (Pa)	222.3	-	71.2	-	-
% Difference	2%	-	24%	-	-
Simulation No. T15 – Shaft barrel and buntons and pipes including flanges and service cage					
Total calculated pressure loss over shaft length (Pa)	652.2	-	285.0	719.8	-
Calculated pressure loss (per m) (Pa/m)	0.75	-	0.57	0.63	-
Total calculated pressure loss over shaft length (CFD) (Pa)	627.8	-	214.7	426.8	-
Measured pressure loss (per m) (CFD) (Pa/m)	1.44	-	1.26	0.68	-
Unaccounted pressure losses (Pa)	247.5	-	70.1	1.6	-
% Difference	4%	-	25%	41%	-

The pressure losses noted in these tests once again show a significant decrease in the difference between the pressures calculated from the theory and those calculated from the CFD results. This reduction in the overall difference is again attributed to the 'unaccounted' pressure losses which the CFD results show. The actual increase in the pressure losses in the overall shaft is not significant when the conveyance is in the shaft.

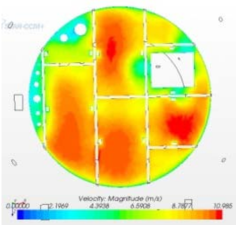
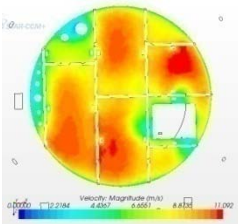
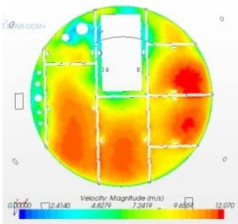
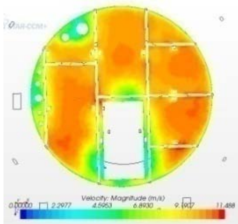
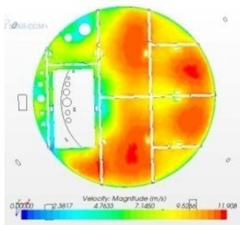






Skip 1 **Skip 2** **Man Cage 1** **Man Cage 2** **Service Cage**

14 Shaft

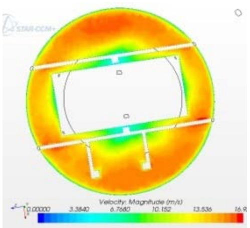
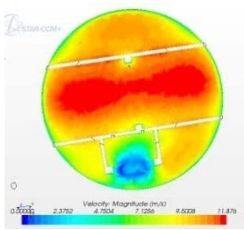




11 Shaft

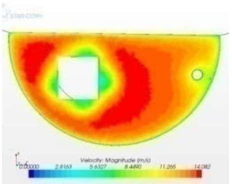
Skip 1 **Skip 2** **Man Cage 1** **Man Cage 2** **Service Cage**

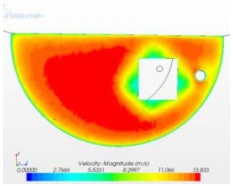
1 Shaft

Man Cage 1 **Counterweight**

11C Shaft





12N Shaft

Figure 5-5: Velocity profiles for simulations 11, 12, 13, 14 and 15

(T11 – Shaft barrel and buntons and pipes including flanges and skip 1; T12 – Shaft barrel and buntons and pipes including flanges and skip 2; T13 – Shaft barrel and buntons and pipes including flanges and man cage 1; T14 – Shaft barrel and buntons and pipes including flanges and man cage 2; T15 – Shaft barrel and buntons and pipes including flanges and service cage)

In the velocity plots of the cross-sections of the various shafts shown in Figure 5-5, a number of interesting facts are apparent.

The velocity profile for each of the plots changes significantly when the different conveyances are placed in the shaft. This is expected. It also highlights the fact that, as the conveyance moves through the shaft, the velocity profile in the shaft changes significantly. The additional pressure losses as the ventilation air is forced in different directions as the conveyance moves through the shaft have not been calculated here. This constant change in direction could account for the additional losses that are apparent from the measured tests and those losses calculated for the CFD analysis and the theoretical analysis.

5.2 Summary and Conclusions from the CFD Simulation Results

Overall, the results of the individual sections of the CFD simulations showed little agreement with those of the theoretical calculations for the initial simulations. There are potentially a number of reasons for this which will be discussed in more detail here. The most importance factor which must be borne in mind are the inaccuracies inherent in the calculations. These are quoted to have an accuracy ± 15% for the calculation of the pressure losses resulting from the shaft wall. (See section 3.2.1.1).

The initial simulations (T01 to T10) were completed in such a way as to allow the evaluation of the individual contributors to the overall shaft pressure drops, as well as to evaluate the effect of these being combined.

It is interesting to note that the initial simulations (T01 to T07) showed very little correlation between the theoretical calculations and those derived from the CFD analysis. The same variables were used in the overall evaluation of both of the techniques.

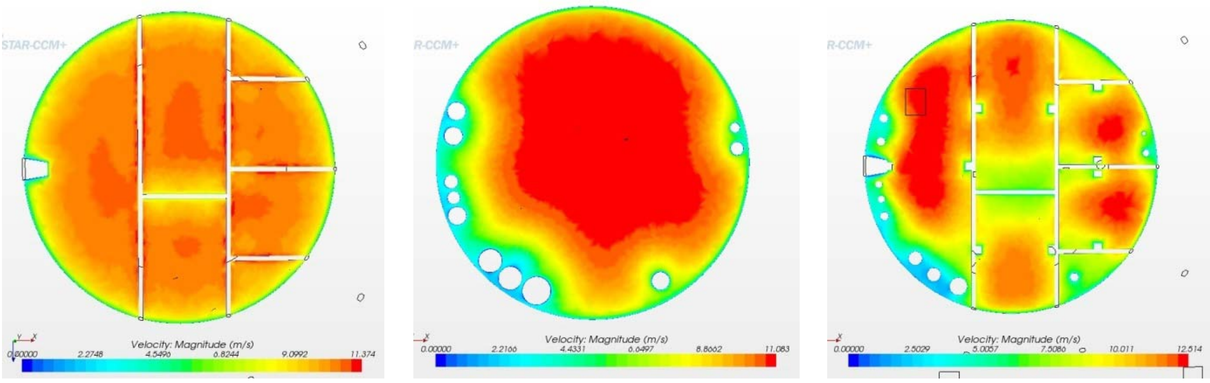
The evaluation of the contribution that the buntons make to the overall friction losses also showed little correlation with the calculated data. It can be seen, however, that the correlation between the theory and the CFD results improves as the complexity of the bunton arrangement increases. It is also significant that the C_D calculated from the CFD data is closest to the assumed value with the single bunton in the shaft. This accuracy decreases in simulation T03 and again increases with simulation T04. This is attributed primarily to the interference factor which is included for the calculation of the theoretical pressure loss. The C_D's for the CFD results calculated without this factor are significantly lower than those assumed for the theoretical evaluation. This does show the importance of including the effect from adjacent buntons when calculating the overall drag coefficient. However, as the differences in the drag coefficient between the assumed values and those calculated from the CFD do not match the percentage differences noted from the pressure drops over the section considered, it does raise a concern as to the accuracy of the factors used for the theoretical evaluation.

In addition, once the pressure losses from the shaft barrel have been removed, there is only a marginally better correlation between the theoretical and the CFD calculations (approximately 2% better) in these initial tests.

The correlation between the theoretical results and the CFD results also showed differences. In simulation T05, the anticipated pressure drops from the theory were very low, with the exception of the 11 shaft. This difference was attributed primarily attributed to the two large pipes in the 11 shaft cross-section. The CFD results, however, showed an even smaller pressure loss. In the case of the results for the 1 and 12N shafts, this result was negative, thus showing that there was a reduction in the pressure drop over these shafts. This negative value was obtained once the pressure losses from the shaft barrel simulation had been subtracted from the simulation T05 pressures. This negative value persisted in the simulation T06 results. Both of these shafts have fewer pipes than the 14 shaft or the 11 shaft. This result is consistent with the observations made by Bromilov (1960). In this paper he noted that there seems to be a small decrease in the pressure losses when pipes are included in the shaft cross-section. However, the above results seem to indicate that this effect is disappears after a certain additional number of pipes have been added in the shaft.

Simulation T07 (i.e. when the pipes are assumed to be flanged) showed significant increases in the pressure losses for all the shafts for the CFD analysis. However, even with the flanges included in the simulation, there is still a significant difference between the calculated pressures losses and those from the CFD simulations.

Simulations T08, T09 and T10 showed significantly better correlations between the theoretical pressure losses and those of the CFD analysis. The theoretical analysis relies on the arithmetic addition of the Chezy-Darcy friction factors being contributed by the various items discussed above. However, the CFD analysis showed different results. To try and discern the reason for this, the pressure losses calculated for the previous tests for the piping and buntons were subtracted from the overall pressure value. This showed an additional unaccounted for pressure loss of approximately 30% of the overall pressure loss. The only reason that could be found for this pressure loss is the interaction between the various components in the shaft. This is not consistent with the theory and indicates that the friction losses for the various components cannot be added to obtain the final Chezy-Darcy friction factor. Figure 5-6 shows the velocity profiles over the shaft cross-sections for the various configurations. These cross-sections provide indicative information as to the reason for the additional pressure losses. The nominal ventilation velocity for this shaft is 10 m/s.



Buntons Only in Cross-section (Simulation T04) | **Piping Only in Cross-section (Simulation T07)** | **Piping and Buntons in Cross-section (Simulation T10)**

Figure 5-6: Velocity profiles for simulations T04, T07 and T10

(T04 – Shaft barrel and full bunton set; T07 – Shaft barrel and pipes including flanges; T10 – Shaft barrel and buntons and pipes including flanges)

The final evaluation relates to the placement of the skips and cages. In this instance there is good correlation between the conveyances and the theoretical data. It must, however, be noted that this correlation includes the unaccounted pressure losses. These still make up approximately 30% of the total pressure loss. The overall pressure loss as a result of the cages from the conveyance is not large, assuming each of the conveyances is alone in the shaft. This is attributed to the fact that none of the conveyances in the shaft is considered to be especially large in comparison with the shaft size. The maximum coefficient of fill was 30%.

5.2.1 Conclusions from the CFD Simulation Results

The following specific conclusions can be drawn from the CFD simulations:

1. The CFD simulation results for the various shafts containing only the buntons or the pipes show little correlation with the theory. These results are however on the extremity of the accuracies shown for the calculations.
2. The inclusion of pipes in the shaft resulted in a small decrease in the overall pressure drop in the shaft. This decrease was only apparent in the shafts that had comparatively fewer pipes. The expected decrease in the pressure drop seems to apply only when the total number of pipes is below a certain limit.
3. The small pressure drops as a result of pipes being included in the shaft are not apparent when the pipes are assumed to be flanged. In this instance there is an increase in the overall pressure drop.
4. The calculation of the pressure drop for the buntons is highly dependent on the interference of each bunton set with the others, as well as on the selected coefficient of drag. This interference factor has been included in the calculation.
5. The overall correlation between the pressure drops predicted by the theory and those taken from the simulations showed significantly better correlation once the complexity of the buntons and the fittings within the shaft increased. This emphasised the interrelated nature of the buntons and fittings in the shaft cross-section. It also highlighted the deficiencies in the current theoretical analysis techniques.
6. The theoretical calculations of the pressure losses resulting from the conveyances in the shaft showed good correlation when compared with those predicted by the simulation results.