Increasing mixing in a simple elbow

1- Introduction and Problem statement

Malekpour et al. [1] showed that a simple elbow with an air vent, which is installed on top of a drop shaft, admits considerable amount of air into the system (Figure a-1). The negative pressure at a high point inside the elbow is the main reason for admitting air into the system. The negative pressure is due to the hydraulic grade line which fall below the pipe`s centerline. This system is very simple and competitive with other systems such as drop shaft with a Double Vortex Inlet (DVI) [1 and 2]. Malekpour et al. [1] also performed a 3D two-phase flow analysis by Fluent software for simple elbow and the results showed that the air partly separate from the water flow even in the end of drop shaft. By increasing the mixing and the time mixing, this system will be appropriate to use in sewer networks.
This study explain how by using the spiral blades in the drop shaft of elbow, the mixing increase significantly. In addition, the other parameters that may be having influences on the air discharge are examined. Figure (a-1) shows the cross section of a simple elbow that is using in this research. In addition, in this model for increasing the mixing, two spiral blades are added to the middle of drop shaft. Two set of spiral blades have opposite directions, therefore the mixing will increase more (Figure b-1).

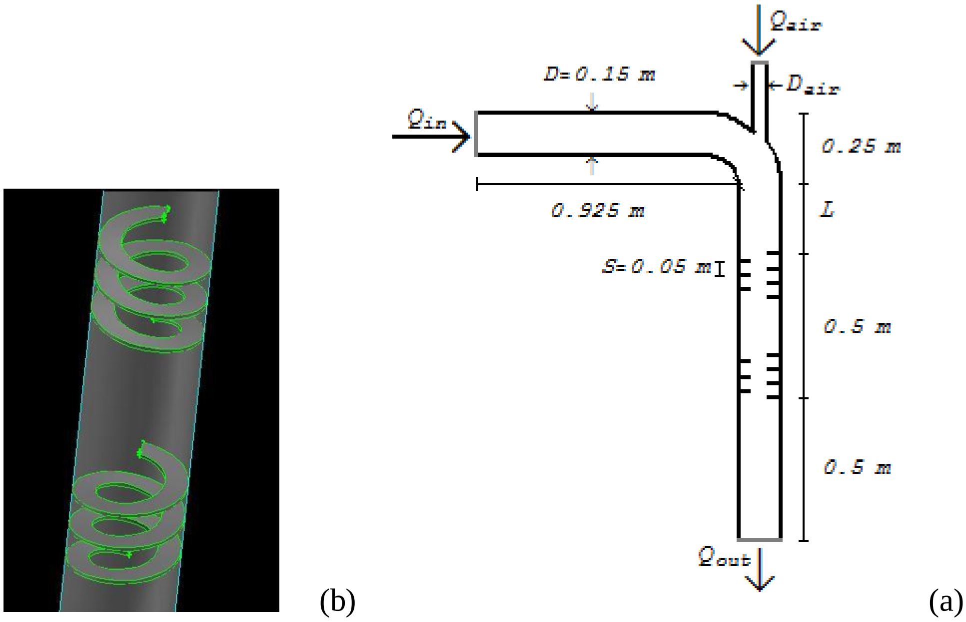

Figure 1. A simple elbow with an air vent.

Table 1 shows the results of the model with and without spiral blades. In these models, the width of blade (*B*) and the inflow velocity are considered 2 cm and 1 m/s (Q_{in}= 17.66 l/s), respectively. The air discharge from 0.0641 l/s for elbow without blades decreased to 0.0218 l/s for elbow with blades. The decreasing of the air inflow discharge is about 66%. In addition, the mixing is going to be in a better state with the spiral blades because the Weighted Average of Volume Fraction (*WAVF*) is about 0.5. Figure 2 shows the flow cross sections of two models. In Figure (a-2) air mixed with the flow after getting contact to the blades. However, in Figure (b-2) the separation air of water is clear along the drop shaft.

Table 1. Mixing in the elbow with and without spiral blades
, Q_{in}= 17.66 l/s, L=0.25 m, B =2 cm, S=5 cm and D_{air}=5 cm

Spiral blades	Q_{air} (l/s)	Weighted Average of Volume Fraction	
		Air	Water
No	0.0641	0.774	0.226
Yes	0.0218	0.511	0.489

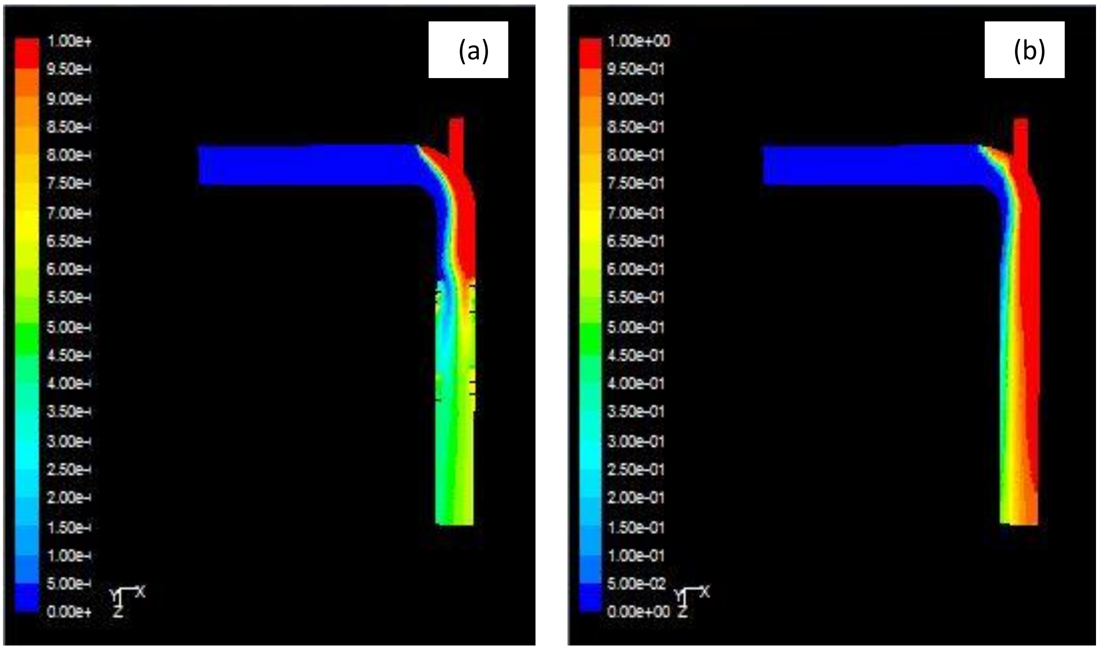

Figure 2. Mixing in the elbow a) with and b) without spiral blades

2- Effective parameters

The following parameters have influence on the air discharge (Q_{air}) and *WAVF* (which is an indicator of mixing intensity):

- Inflow velocity V or Inflow Discharge Q_{in}
- Diameter of elbow, D
- Diameter of air vent, D_{air}
- Length of drop shaft before of blades, L
- Number of blades in each group, N
- Width of blade, B
- Step of spiral blade, S

So by choosing D and V as the parameters to determine the non- dimensional parameters for modeling the air discharge with best mixing, it is resulted that:

$$\frac{Q_{air}}{Q_{in}} = f\left(\frac{B}{D}, \frac{D_{air}}{D}, \frac{L}{D}, \frac{S}{D}, \mathrm{Fr}, N\right) \quad (1)$$

Based on the model`s geometry, it is clear that the true flow pattern in the system has strong three-dimensional characteristics, therefore the model should be analyzed by a three dimensional hydraulic analysis. Moreover, in order to consider the air flow in the system, a two-phase flow model is also critical. Generally, several different types of two-phase flow regimes can potentially occur in systems, including bubbly flow, droplet flow, slug flow and stratified flow [3]. The device system is same as the DVI, consequently the large number of small and diffused bubbles is considered.

Several different types of two-phase flow models exist, including the volume of fluid (VOF), Eulerian and mixed flow models. The mixed flow model is the most compatible model that can be used to resolve bubbly flow motion and therefore is the preferred and employed model for this study. In this research the Fluent V6.3 [4] is used to have a numerical analysis. A three dimensional algebra model with slip velocity and with the standard $k-\varepsilon$ turbulence model are selected as the computational model within Fluent. The considered fluid is water. Totally 34 models were analyzed.

Influence of B/D on Q_{air}/Q_{in} and *WAVF*

To investigate the effect of blade width (B) and also number of blade in each group (N) on the air discharge (Q_{air}) and mixing, 15 models were analyzed (Table 2). In all models the inflow velocity was constant (V=1 m/s and Q_{in}= 17.66 l/s) and L=25 cm, D=15 cm, S=5 cm and D_{air}=5 cm.

Table 2. Q_{air} and *WAVF* in the elbow,
Q_{in}= 17.66 l/s, L=25 cm, D=15 cm, S=5 cm and D_{air}=5 cm

N	*B* (*cm*)	Q_{air} (l/s)	*Weighted Average of Volume Fraction*	
			Air	*Water*
3	1	0.0423	0.677	0.323
	2	0.0218	0.511	0.489
	3	0.0054	0.198	0.802
	4	0	0	1
	5	0	0	1
2	1	0.0479	0.7134	0.286
	2	0.0242	0.5223	0.4777
	3	0.0068	0.2370	0.7630
	4	0	0	1
	5	0	0	1
1	1	0.0504	0.721	0.279
	2	0.0259	0.533	0.467
	3	0.0081	0.275	0.725
	4	0	0	1
	5	0	0	1

Figure 3 shows variation of Q_{air}/Q_{in} versus B/D with N=3, 2 and 1. The air discharge decreased when the blade width increased. Variation of two parameters is near to linear (Figure 3). When the width of blade is going to 4 cm and more, the middle hole of blades (Figure b-1) is small and loss of energy is high so the negative pressure at a high point inside the elbow is change to positive pressure and the fluid flows from the air vent and air discharge is zero. Therefore, it is resulted to avoid this condition and to limit the width of blade. In addition, the sewer flow has solid pieces, which cannot pass through the spiral blades. The middle hole of blades is the best way to flow the fluid with big solid pieces.

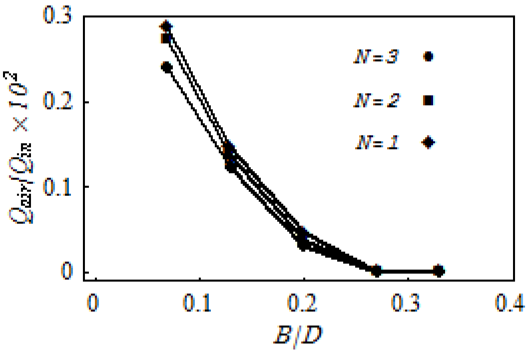

Figure 3. Variation of B/D - Q_{air}/Q_{in}

Figure 4 shows variation *WAVF* versus B/D with N=3, 2 and 1, based on the data from Table 2. The best mixing (*WAVF* near to 0.5) in all conditions have been resulted where the width of blade is 2 cm or *B*/*D*=0.13. In this situation, the middle open area (hole) is about %54 of the cross section of drop shaft area (pipe).

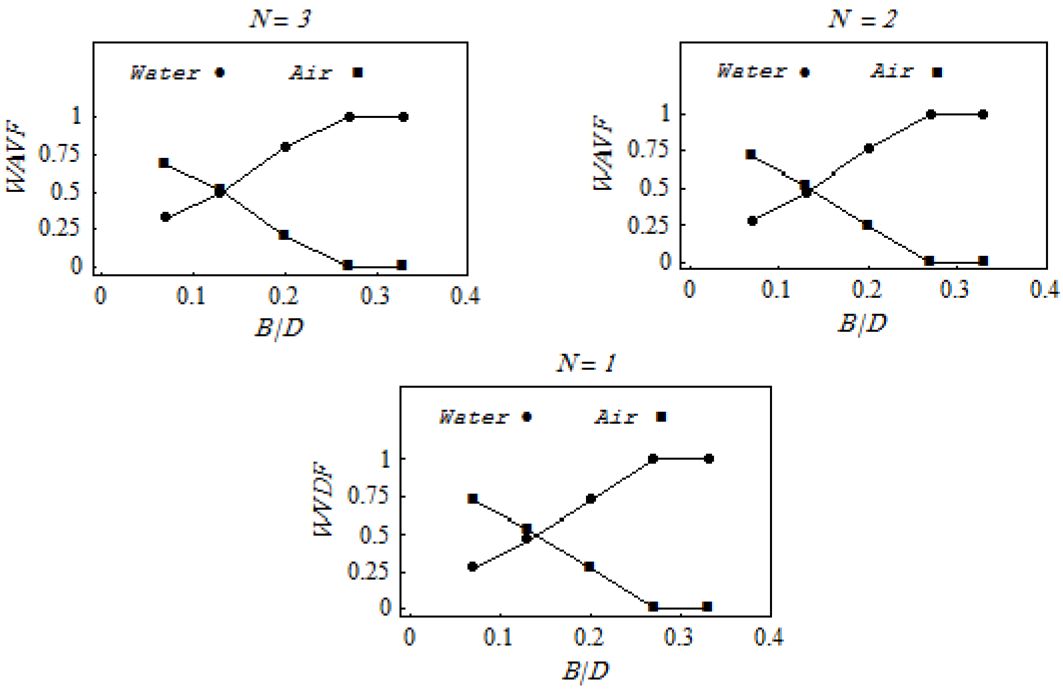

Figure 4. Variation of B/D - *WAVF*

Influence of N on Q_{air}/Q_{in} and *WAVF*

By decreasing the number of spiral blade in each grope of blades, the air discharge is increased but it is not considerable (Table 2). In addition, the *WAVF* of air is also increased which shows the separation of air from water. The variation of *WAVF* for B=2 cm and N=3,2 and 1 shows in Figure 5. The variation is small but the best results achieved for N=3. Therefore, the number of blades is not very important in estimation of the air discharge but it is better to consider not less than three blades in each group.

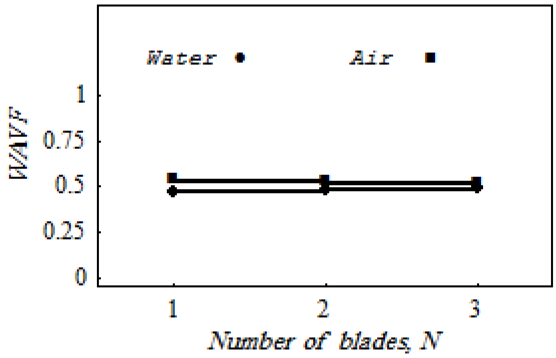

Figure 5. Variation of N - *WAVF*, B=2 cm

Influence of D_{air}/D on Q_{air}/Q_{in} and *WAVF*

Four models were analyzed with different air vent diameters to study influence of air vent diameter on the air vent discharge and mixing when the other parameters were considered constant. Table 3, shows the assumptions and results.

It is obvious before the results are attained, that the air discharge won't have high variation. The viscosity of air against the sewer is very low so, the loss of energy based on the airflow is very small. Therefore, the negative pressure in high point of elbow is not changed considerably when the air vent diameter is changed and therefore, the air discharge won't have great change. By decreasing the diameter of air vent, the velocity of air is increased so the negative pressure and the air discharge are reduced (Table 3). The *WAVF* has very small change with D_{air} (Table 3). As a result, the influence of D_{air} on Q_{air} and mixing is not noticeable.

Table 3. Q_{air} and *WAVF* in the elbow,
Q_{in}= 17.66 l/s, L=25 cm, , D=15 cm , N=3, S=5 cm and B=2 cm

D_{air} (cm)	Q_{air} (l/s)	*Weighted Average of Volume Fraction*	
		Air	*Water*
3	0.0208	0.499	0.501
4	0.0217	0.508	0.492
5	0.0218	0.511	0.489
6	0.0222	0.515	0.485

Influence of L/D on Q_{air}/Q_{in} and *WAVF*

For studying the effect of length of drop shaft on Q_{air}/Q_{in} and mixing, 15 models were analyzed (Table 4). The length of the drop shaft was 1.25, 1.5 and 1.75 meter which is related to L=0.25, 0.5 and 0.75 meter, respectively. The width of blade was also considered variable, B= 1, 2, 3, 4 and 5 cm. The variation pattern of Q_{air}/Q_{in} - B/D as shows in Figure 6 is linear, same as Figure 3. The difference between lines in Figure 6 are considerable where B=1 cm (B/D=0.067) and in this condition the mixing is not good. With B=2 cm (B/D=0.13) the mixing have the best state for L=0.25, 0.5 and 0.75 meter. By increasing the length of drop shaft before the blades, the air discharge is slowly increased and difference between water and air *WAVF* is increased. Figure 7 shows this difference variation for B=2 cm. Therefore, the length of drop shaft before the blades has not significant influence on Q_{air}/Q_{in} and mixing.

Table 4. Q_{air} and *WAVF* in the elbow,
Q_{in}= 17.66 l/s, D=15 cm, S=5 cm, N=3 and D_{air}=5 cm

L (cm)	*B* (cm)	Q_{air} (l/s)	Weighted Average of Volume Fraction	
			Air	*Water*
25	1	0.0423	0.677	0.323
	2	0.0218	0.511	0.489
	3	0.0054	0.198	0.802
	4	0	0	1
	5	0	0	1
50	1	0.0501	0.715	0.285
	2	0.0234	0.523	0.477
	3	0.0062	0.220	0.780
	4	0	0	1
	5	0	0	1
75	1	0.0549	0.723	0.277
	2	0.0256	0.542	0.458
	3	0.0082	0.273	0.727
	4	0	0	1
	5	0	0	1

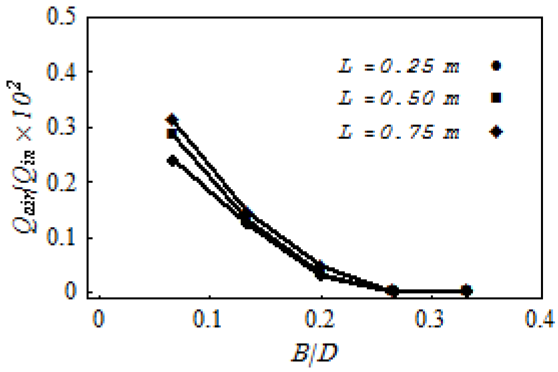

Figure 6. Variation of B/D -Q_{air}/Q_{in}

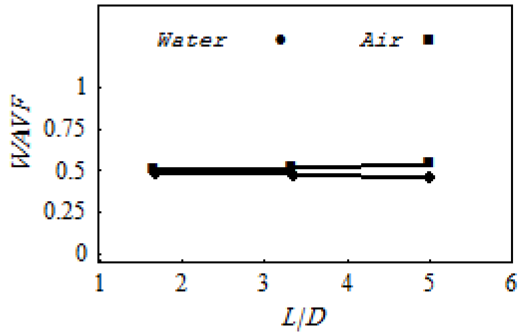

Figure 7. Variation of L/D -*WAVF*, *B*=2 cm

Influence of *S*/*D* on Q_{air}/Q_{in} and *WAVF*

The step of spiral blades in previous models was considered 5 cm or *S*=*D*/3. The possibility of passing flow between the blades is important for increasing mixing in elbow. Three models with *S*=4, 5 and 6 cm are analyzed to clear the effect of step of blades on air discharge and mixing (Table 5). Figures 8 and 9 are drawn based on the analyzed results that mentioned in Table 5. These figures shows that the influence of the step of baled is not considerable in mixing and Q_{air}. Table 5 shows that the difference between the results for *S*=5 and 6 are insignificant so *S*=*D*/3 is recommended for step of spiral blades.

Table 5. Q_{air} and *WAVF* in the elbow,
Q_{in}= 17.66 l/s, *D*=15 cm, *N*=3, *L*=25 cm and *B*=2 cm

S (*cm*)	Q_{air} (l/s)	*Weighted Average of Volume Fraction*	
		Air	*Water*
4	0.0229	0.517	0.483
5	0.0218	0.511	0.489
6	0.0215	0.509	0.491

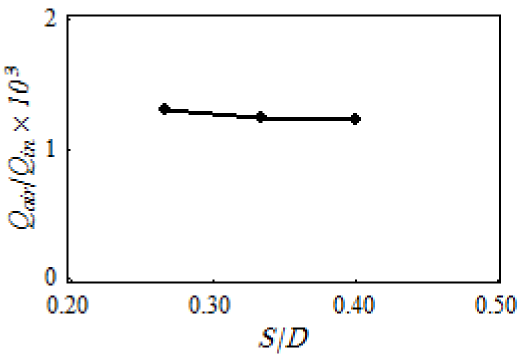

Figure 8. Variation of S/D -Q_{air}/Q_{in}

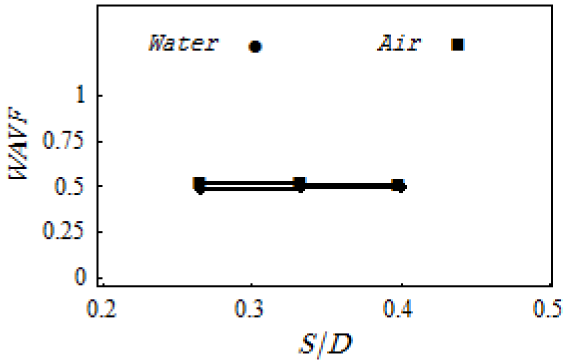

Figure 9. Variation of S/D -*WAVF*

Influence of Fr on Q_{air}/Q_{in} and *WAVF*

In all models which are analyzed in previous sections, the velocity is considered constant, V=1 m/s (Q_{in}=17.661 l/s). To study the effect of inflow velocity on Q_{air}/Q_{in} and mixing, five models are analyzed with different velocity (Table 6). Figures 10 and 11 are made by using the data from Table 6. Figure 10 shows by increasing velocity or Fr number, Q_{air} or Q_{air}/Q_{in} is decreased, this variation is nearly to linear change. Figures 11 is a clear figure of variation of Fr versus *WAVF*. The best mixing is resulted for Fr=0.825 (V=1 m/s). Figure 12 shows the situation of flow in the elbow for two velocities. Therefore, the Fr has an effect to the air discharge and mixing. The relationship of these parameters with Fr can be considered linear.

Table 6. Q_{air} and *WAVF* in the elbow,
D=15 cm, N=3, S=5 cm, L=25 cm and B=2 cm

V m/s	Fr	Q_{in} (l/s)	Q_{air} (l/s)	Q_{air}/Q_{in} $\times 10^2$	*Weighted Average of Volume Fraction*	
					Air	*Water*
0.5	0.412	8.795	0.0322	0.366	0.756	0.243
0.75	0.618	13.192	0.0276	0.209	0.638	0.362
1.0	0.824	17.661	0.0218	0.123	0.511	0.489
1.25	1.030	21.986	0.0161	0.073	0.386	0.614
1.5	1.236	26.384	0.0114	0.043	0.265	0.735

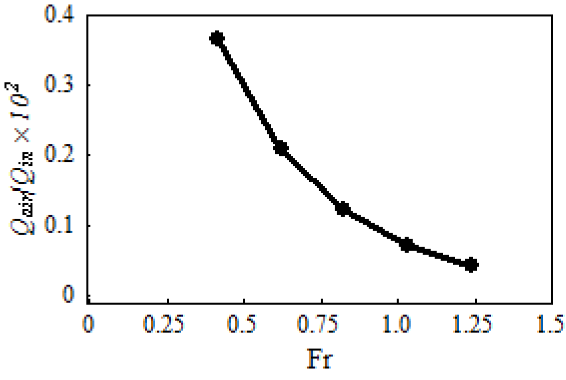

Figure 10. Variation of Fr - Q_{air}/Q_{in}

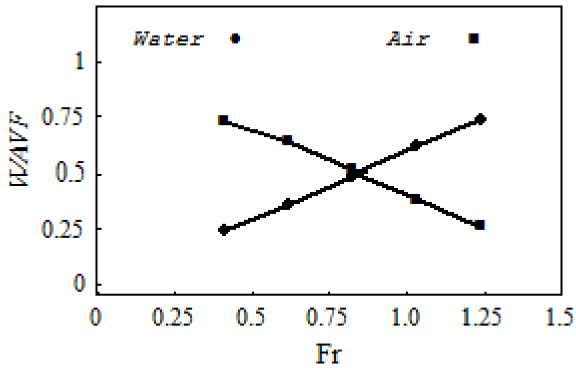

Figure 11. Variation of Fr - *WAVF*

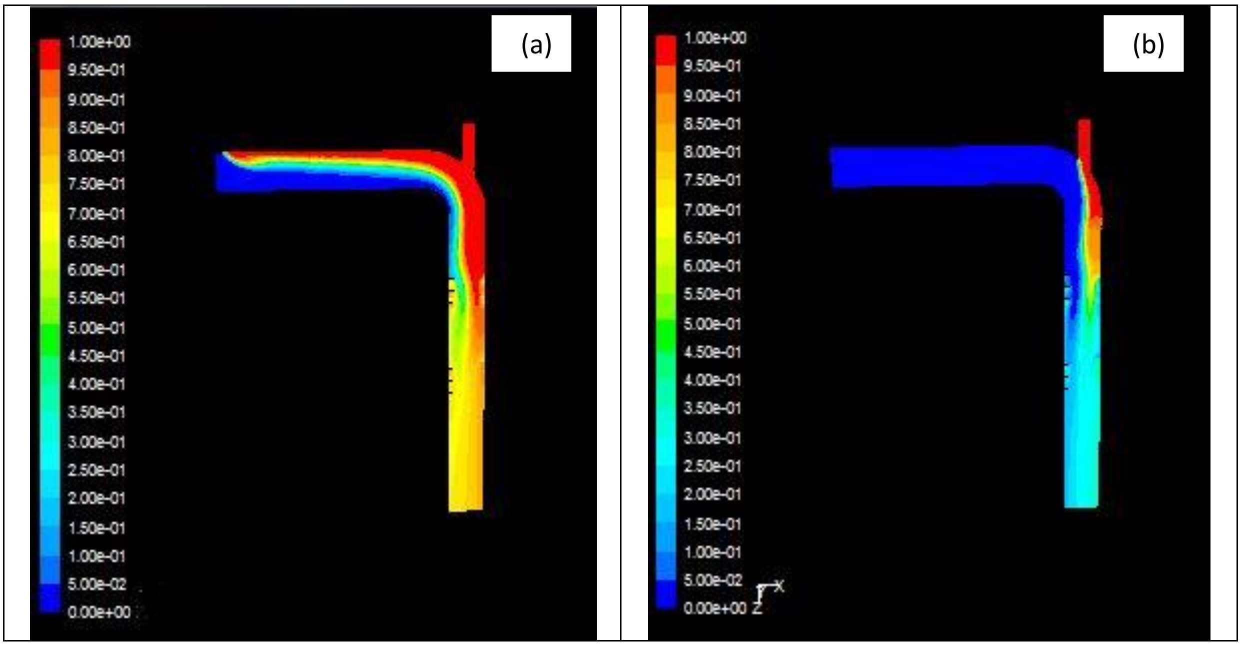

Figure 12. Flow in the elbow a) V=0.5 m/s and b) V=1.5 m/s

3- Conclusion

Adding spiral blades to simple elbow increased valuably the mixing in elbows. In addition, this is an easy and economical way in comparison with other methods to increase the mixing. This model lets the solid parts of sewer pass easily the drop shaft.

The parameters, which are mentioned in equation (1), may have effect on the air discharge and mixing which were studied in previous section. The parameters D_{air} (diameter of air vent), L (length of drop shaft before of blades), N (number of blades in each group) and S (step of spiral blade) did not have a great effect on the air discharge and mixing. However, B (width of blade) and Fr have considerable effects and may result:

$$\frac{Q_{air}}{Q_{in}} = f\left(\frac{B}{D}, \mathrm{Fr}\right) \tag{2}$$

Although the results and especially Figures 10 and 3 showed that the variation of Q_{air}/Q_{in} versus B/D and Fr are not linear but these are closed to the linear variation so this relationship can be considered linear:

$$\frac{Q_{air}}{Q_{in}} = Linear\,equation\left(\frac{B}{D}, \mathrm{Fr}\right) \tag{3}$$

This study was conducted only on elbow with small drop shaft. For obtaining the optimum air discharge and mixing, this study recommend $S=D/3$, $N>3$, $D_{air}=D/3$, $L=0.25$ m, Fr=0.8 and $B/D=0.13$ (which is equivalent with the middle open area (hole) is about %54 of the cross section of drop shaft area).

4- Refrences

[1] Malekpour, A., Karney, B., St-Aubin, R. and Radulj, D. (2013). "Exploring the underlying physics of the double vortex insert device by CFD.", ?????

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