Entrance Tank Flow Control: High Flow Modifications

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Problem Definition

Introduction

I am working on modifications to the Agua Clara design code for high flow plants, with a focus on flow control in the entrance tank. Flow control in the entrance tank refers to the ability of the plant operator to drain influent water. This may be necessary if extremely turbid water from a recent storm is entering the plant, or if excessive flow is entering the plant. The current design for flow control in the entrance tank features one bronze gate valve on the side of the tank (see Figure 1 below), that can be opened to convey influent water through a pipe and into the drain channel if necessary .

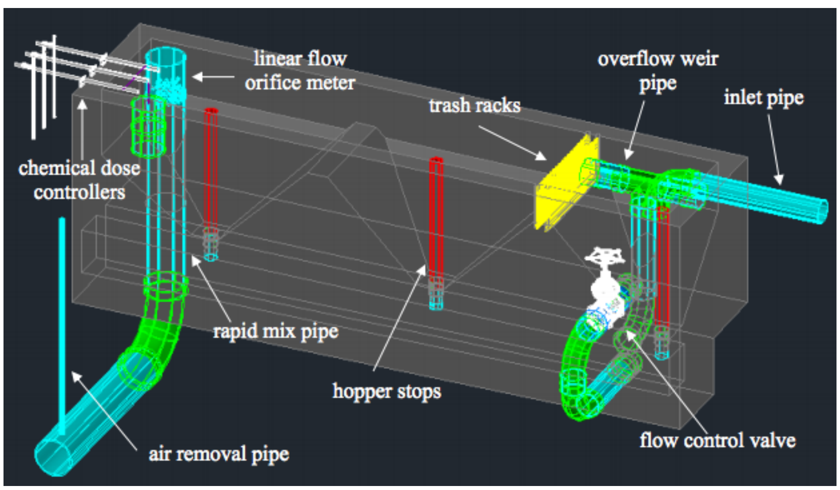

Figure 1: Existing Design for Entrance Tank (18 L/s plant)

The most recent Agua Clara design code sizes this pipe leading to the drain channel with adequate capacity to carry the entire plant flow if needed. This design is sufficient for smaller Agua Clara plants. In high-flow Agua Clara plants, however, a problem arises as the diameter of the pipe required to drain the entire plant flow increases. In these cases, the size of the bronze gate valve must increase to fit onto the pipe. This creates a cost restraint, since bronze gate valves tend to get significantly more expensive at larger sizes. Thus, I intend to engineer a cost-effective solution for the entrance tank flow control mechanism at high flow rates that will ultimately be reflected in the design code. I am not necessarily focusing on solutions that allow the entire plant flow to be drained, as this can be acheived by pulling the drain stopper pipes (hopper stops in Figure 1) out of the entrance tank hoppers. Rather, I am focusing on providing plant operators the ability to control the incoming flow rate with maximum precision. Alternatives being considered include the use of different valve types, the use of multiple, smaller-size valves in parallel, and the use of Fernco flexible couplings on the top end of the drain stopper pipes.

Design Details

The existing code for the entrance tank calculates the required diameter of the flow control valve (ND.EtFlowControl). This value specifies the size of the valve that is displayed when plant drawings are generated by the Agua Clara design server. This value directly effects my analysis as the cost constraint is driven primarily by the diameter of this valve. Alternative designs featuring the use of multiple, smaller-size valves in parallel are designed to have an equal flow capacity as the single valve currently used.

Another alternative being considered is the use of Fernco flexible couplings on the top end of the drain stopper pipes in the entrance tank. The entrance tank code was used to determine that the diameter of these stopper pipes (ND.EtDrain) is fixed at 3 inches for all flow rates. Using the Q.PipeTotal algorithm in the Fluids Function, the flow capacity of the 3-inch stopper pipes was determined to be 13.4 L/s. After some discussion, the 3-inch stopper pipe diameter was assumed to be arbitrary. Thus, in cases in which the drain flow is limited by this pipe size, an increase to 4-inch diameter pipe was utilized. Flow capacities for relevant coupling sizes (equipped as adjustable weir were determined using Q.rectweir algorithm in the Agua Clara Fluids Function. This algorithm assumes rectangular geometry, while the coupling is actually circular. The validity of this assumption may be further investigated in the future. In the existing entrance tank code, it was determined that for plant flow rates of 14 L/s or greater, the number of entrance tank hoppers (N.EtFullHoppers + 2) increases from 3 (2 half-full, 1 full) to 4 (2 half-full, 2 full). There is one drain stopper pipe and drain for each hopper. The half-full hopper farthest to the left on Figure 1 is not to be utilized for flow control purposes due to the potential influence on the Linear Flow Orifice Meter (LFOM).

If any of the alternative designs being considered are to be ultimately reflected in the entrance tank code, the existing code for the flow control valve and piping to the drain channel will be eliminated. For a given flow rate, the entrance tank code would produce the corresponding recommended design. The existing AutoCAD drawing code would also need to be changed in order for any alternative designs to be reflected in drawings generated by the Agua Clara design server.

Documented Progress

Analysis of Current Design

I assessed potential solutions that featured the use of multiple, smaller-size valves to avoid the use of bronze gate valves at sizes that are too expensive. First, I determined the size of the valve at which the price becomes overly expensive. Table 1 below shows typical pricing of bronze gate valves in Honduras, as provided by Drew Hart.

Valve Size (in)	Price (USD)
1”	$24.50
2”	$39.20
3”	$161.70
4”	$171.50
6”	$588.00

Table 1. Typical pricing of bronze gate valves in Honduras

From this table, I deduced that the bronze gate valves prices surge at sizes after 2 inches and 4 inches, becoming overly expensive. It is also important to note that the largest size valve for which a price quote could be obtained in 6 inches. Valves larger than 6 inches are considered a specialty item, which means they are hard to locate and even more overpriced. The lack of cost information for larger valves has been a key limitation in my analysis since there is nothing to compare my alternative designs to for flow rates requiring a valve larger than 6 inches. Additionally, I have been informed by Drew Hart that the pricing on valves of any size are largely variable depending on the location and supplier. Thus, the prices shown in Table 1 are merely being used as a benchmark in my analysis. In practice, quotes should be obtained on a case-by-case basis, and only then should the cost of alternative designs be compared.

Using the $D_{\text{PipeChannel}}$ function in the “Fluids Functions” file of the Agua Clara source code, I determined the range of flow rates expected for each diameter. The results are displayed below in Table 2.

Diameter of Flow Control Pipe (in)	Range of Flow Rates (L/s)
2”	<1
3”	1-2
4”	2-5
6”	5-13
8”	13-25
10”	25-44

Table 2. Flow Rate Ranges for each diameter

Analysis of Alternative Designs

This table allowed me to determine the number of smaller-size valves would be required in parallel to accommodate for larger flow rates. This information allowed me to formulate cost estimates for this design alternative over a range of flow rates.The cost estimates developed include the price of the valves, fittings, and additional length of pipe required for the manifold. The prices for fittings used reflect the price displayed on McMaster Carr’s online catalog for standard-wall white PVC pipe inline reducing tees. The McMaster Carr online catalog was also used to estimate the price of PVC pipe for the additional length of manifold required due to the additional valves, and the price of the PVC gate valves. Similar analyses were performed to estimate the cost of solutions featuring the use of PVC gate valves, ductile iron butterfly valves.Butterfly valves are more effective for this purpose as they can be used to regulate flow, where as gate valves are usually completely opened or closed. Figure 2 below displays the cost of each alternative design assessed over the range of flow rates for which adequate cost information was available. The raw data can be found in Table 3 of the Appendix.

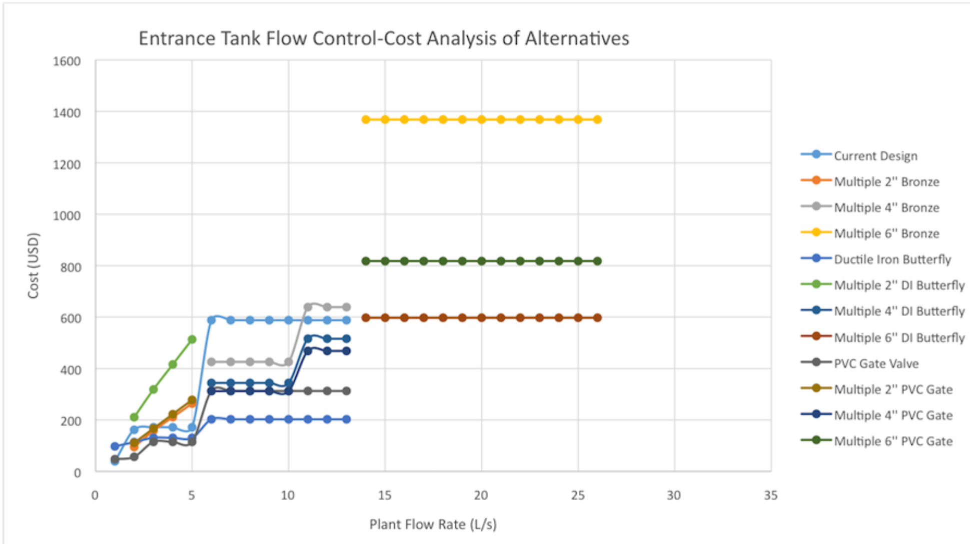

Figure 2: Cost of Flow Control Solutions using Valves over Range of Flow Rates

Next, another alternative was considered that does not feature the use of any valves in the entrance tank. This alternative design utilizes Fernco flexible couplings on one or more of the entrance tank drain stopper pipes for an adjustable, economical option. The drain stopper pipes in the entrance tank are currently fixed at a diameter of 3 inches for all flow rates (according to EtFlocSedFi file in Agua Clara Source Code), and can be pulled out of place to convey the entire plant flow into the drain channel. In the proposed design, a Fernco flexible fitting (reducing coupling) would be attached to the top end of these stopper pipes. In the case that the operator wants to drain water coming into the entrance tank, the flexible fitting could be lowered down the pipe so that the top of the fitting is below the water level in the tank to dump the influent water. This configuration allows vertical adjustments approximately as large as the length of the coupling (could stack multiple couplings to increase). The draining mechanism is displayed below in Figure 3.

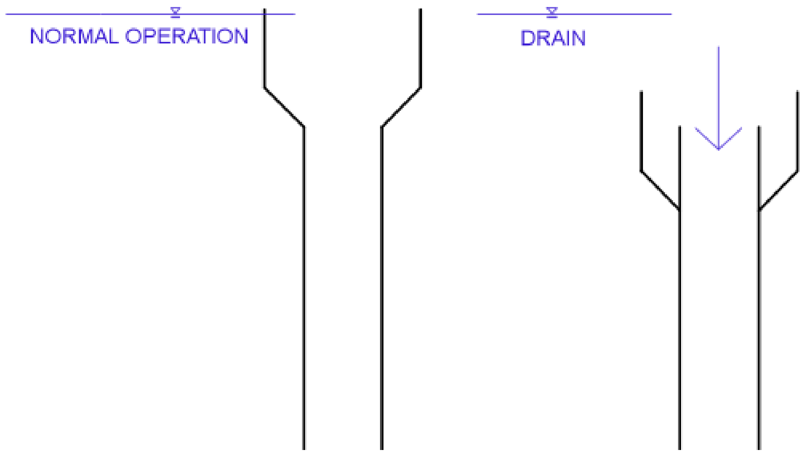

Figure 3: Draining Mechanism-Flexible Coupling on Drain Stopper

A key constraint on this design relates to the height of water above the inlet to this configuration when draining the flow. It was determined that head loss would be too large for this configuration when the height above the top of the inlet was greater than one-third of the top diameter. This constraint (H.weir=D/3) was used when determining the capacity of this configuration to drain the influent water using Q.rectweir function in the Agua Clara Fluids Function (assumes rectangular geometry, actually circular). The resulting flow capacities for numerous coupling sizes and their respective prices (from Fernco Price List) are displayed below in Table 3.

Coupling Size	Flow (L/s)	Cost ($)
3" x 3"	1.8	13.63
3" x 4"	3.7	18.37
3" x 5"	6.5	37.93
3" x 6"	10.2	51.85
6" x 8"	20.9	67.76
4" x 8"	20.9	92.75

Table 3: Flow Capacity and Cost of Each Relevant Coupling Size

Additionally, using Q.pipetotal from the Fluids Function, the flow capacity of the 3-inch drain stopper pipe was determined to be **13.4 L/s.** Thus, the capacity of this drain configuration is limited by the size of the drain stopper pipe when the top diameter of the reducing coupling is greater than 6 inches. This analysis assumes that this fixed value of 3 inches for the diameter of the stopper pipes is arbitrary. Thus, an increase to 4 inches (capacity of 24.3 L/s) is utilized in cases where the flow is limited by this pipe. This information, along with the information in Table 3 above, can be employed to develop optimal coupling sizes and configurations for the entire range of plant flow rates.

All of the competitive coupling combinations and configurations that were analyzed are shown in Table 2 of the Appendix. These combinations were generated by considering cost per flow, the number and spacing of drainable flow increments (how much control operator has over flow rate), and maximum drainable flow. Drainable flow increments include every potential flow control permutation (combinations of which couplings are lowered to drain) that the operator can employ for a given coupling use. For a greater number of increments, a plant operator has more control over the incoming flow. It is also ideal to have relatively equal spacing between increments so that each increment is useful.

Finally, all of the alternative designs were compared with the current design. Recommended designs for all flow rates are included below in Table 4.

Range of Flow Rates (L/s)	Recommended Design	Estimated Cost ($)
2-3	1 3" x 3" Fernco	13.63
4-5	2 3" x 3" Fernco	27.26
6-7	1 3" x 3", 1 3" x 4" Fernco	32.00
8	2 3" x 4" Fernco	36.74
9-10	1 3" x 3", 1 3" x 5" Fernco	51.56
11-13	1 3" x 4", 1 3" x 5" Fernco	53.30
14-15	1 3" x 3", 1 3" x 4", 1 3" x 5" Fernco	69.83
16-17	2 3" x 4", 1 3" x 5" Fernco	74.67
18-20	2 3" x 4", 1 3" x 6" Fernco	88.59
21-27	1 3" x 4", 1 3" x 5", 1 3" x 6" Fernco	108.15
28-30	1 3" x 5", 2 3" x 6" Fernco	141.63
31-41	3 3" x 6" Fernco	155.55
42-62	2 4" x 8" Fernco*	185.50
62>	3 4" x 8" Fernco*	278.25
*Designs feature 4" stopper pipes		

Table 4. Recommended Designs

Designs featuring Fernco couplings are preferred over any designs featuring valves, as they permit higher flows at much lesser costs and more "adjustability" for the plant operator.

Future Work

This potential design change still needs to be programmed into the Agua Clara source code for the entrance tank and AutoCAD drawing scripts. Before making any changes in code final, this analysis can be fine-tuned as there are several initial assumptions that can be further investigated. These include the use of Q.rectweir for a circular coupling, the weir head loss constraint setting the maximum height above the weir at one-third the diameter, and the assumption that the diameter of the drain stopper pipe can be increased from 3 inches to 4 inches in limiting cases. Finally, the recommended designs shown in Table 4 above need to be confirmed as the optimal design compared to other alternatives displayed in Tables 1 and 2 in the Appendix.

Appendix

Q (L/s)	D required (in)	Cost existing ($)	Mult 2"	Cost	Mult 4"	Cost	Mult 6"	Cost	Cost DI Butterfly Valve	Cost mult 2"	Cost mult 4"	Cost mult 6"	Cost PVC Gate Valve	Cost mult 2"	cost mult 4"	cost mult 6"
1	2	**39.2**							97.22				47.49			
2	3	161.7	2	94.66					113.89	210.7			**56.83**	111.24		
3	4	171.5	3	158.22					130.56	318.74			**114.73**	166.86		
4	4	171.5	4	210.96					130.56	415.96			**114.73**	222.48		
5	4	171.5	5	263.7					130.56	513.18			**114.73**	278.1		
6	6	588			2	425.84			202.63		343.96		312.8		**312.3**	
7	6	588			2	425.84			202.63		343.96		312.8		**312.3**	
8	6	588			2	425.84			202.63		343.96		312.8		**312.3**	
9	6	588			2	425.84			202.63		343.96		312.8		**312.3**	
10	6	588			2	425.84			202.63		343.96		312.8		**312.3**	
11	6	588			3	638.76			202.63		515.94		**312.8**		468.45	
12	6	588			3	638.76			202.63		515.94		**312.8**		468.45	
13	6	588			3	638.76			202.63		515.94		**312.8**		468.45	
14	8				3		2	1368.2				**597.46**				*817.8*
15	8				3		2	1368.2				**597.46**				*817.8*
16	8				4		2	1368.2				**597.46**				*817.8*
17	8				4		2	1368.2				**597.46**				*817.8*
18	8				4		2	1368.2				**597.46**				*817.8*
19	8				4		2	1368.2				**597.46**				*817.8*
20	8				4		2	1368.2				**597.46**				*817.8*
21	8						2	1368.2				**597.46**				*817.8*
22	8						2	1368.2				**597.46**				*817.8*
23	8						2	1368.2				**597.46**				*817.8*
24	8						2	1368.2				**597.46**				*817.8*
25	8						2	1368.2				**597.46**				*817.8*
26	10						2	1368.2				**597.46**				*817.8*

Table 1: Cost Analysis of Alternative Designs Featuring Valves

Coupling Use	**Maximum Drainable Flow (L/s)**	**Cost ($)**	**Drainable Flow Increments**
1 3" x 3"	1.8	13.63	1 (1.8)
2 3" x 3"	3.6	27.26	2 (1.8, 3.6)
1 3" x 4"	3.7	18.27	1 (3.7)
1 3" x 3", 1 3" x 4"	5.5	32.00	3 (1.8, 3.7,5.5)
2 3" x 3", 1 3" x 4"	7.3	45.53	5 (1.8, 3.6, 3.7, 5.5, 7.3)
2 3" x 4"	7.4	36.74	2 (3.7, 7.4)
1 3" x 3", 1 3" x 5"	8.3	51.56	3 (1.8, 6.5, 8.3)
1 3" x 3", 2 3" x 4"	9.2	50.37	5 (1.8, 3.7, 5.5, 7.4, 9.2)
2 3" x 3", 1 3" x 5"	10.1	65.19	5 (1.8, 3.6, 6.5, 8.3, 10.1)
1 3" x 4", 1 3" x 5"	10.2	53.30	3 (3.7, 6.5, 10.2)
3 3" x 4"	11.1	54.81	3 (3.7, 7.4, 11.1)
1 3" x 3", 1 3" x 4", 1 3" x 5"	12.0	69.83	7 (1.8, 3.7, 5.5, 6.5, 8.3, 10.2,12.0)
2 3" x 5"	13.0	75.86	2 (6.5, 13.0)
1 3" x 4", 1 3" x 6"	13.9	70.12	3 (3.7, 10.2, 13.9)
2 3" x 4", 1 3" x 5"	13.9	74.67	5 (3.7, 6.5, 7.4, 10.2, 13.9)
1 3" x 3", 2 3" x 5"	14.8	89.49	5 (1.8, 6.5, 8.3, 13, 14.8)
1 3" x 4", 2 3" x 5"	16.6	94.23	5 (3.7, 6.5, 10.2, 13.0, 16.6)
1 3" x 5", 1 3" x 6"	16.7	89.78	5 (3.7, 7.4, 10.2, 13.9, 3 (6.5, 10.2, 16.7)
2 3" x 4", 1 3" x 6"	17.6	88.59	5 (3.7, 7.4, 10.2, 13.9, 17.6)
3 3" x 5"	19.4	113.79	3 (6.5, 13.0, 19.4)
2 3" x 6"	20.4	103.70	2 (10.2, 20.4)
1 3" x 4", 1 3" x 5", 1 3" x 6"	20.4	108.15	6 (3.7, 6.5, 10.2, 13.9, 16.7, 20.4)
2 3" x 5", 1 3" x 6"	23.2	127.71	5 (6.5, 10.2, 13.0, 16.7, 23.2)
1 3" x 5", 2 3" x 6"	26.9	141.63	5 (6.5, 10.2, 16.7, 20.4, 26.9)
1 (3" x 6" + 6" x 8")*, 1 3" x 5", 1 3" x 6"	30.1	209.39	7 (6.5, 10.2, 13.4, 16.7, 19.9, 23.6, 30.1)
3 3" x 6"	30.6	155.55	3 (10.2, 20.4, 30.6)
2 (3"x 6"+6"x 8")*, 1 3" x 6"	37.0	291.07	5 (10.2, 13.4, 23.4, 26.8, 37.0)
3 (3"x 6"+6"x 8")*	40.2	358.83	3 (13.4, 26.8, 40.2)
2 4" x 8"**	41.8	185.50	2 (20.9, 41.9)
3 4" x 8"**	62.7	278.25	3 (20.9, 41.8, 62.7)

* Designs feature a 6" x 8" coupling on top of a 3" x 6" flexible coupling. Flow limited by 3-inch stopper pipes.

**Designs assume stopper pipe diameter is increased from 3" to 4"

Table 2: Flow and Cost Data for Relevant Coupling Uses