SUMMARY

There are many problems derived from a reverse flow in a piping system. A solution presented in this paper is the WaStop inline check valve. The paper aims to explain some of the important technical aspects when choosing a check valve, such as choice of materials used to manufacture the valve and pressure losses when in operation.

PROBLEMS CAUSED BY BACKFLOW IN PIPE SYSTEMS.

A pipe system operates on a pressure differential. There has to be a higher pressure upstream relative to downstream, to enable flow in the wanted direction. The differential is created by either a pump or an elevation change or a combination of the two. If the pressure differential becomes negative there will be a flow in the opposite direction.

CAUSES:

- Heavy rain/snowfall, Storm water systems are dimensioned for normal rain. To dimension a system to handle exceptional rain is in practicality impossible, hence in case of heavy rain or snow the system becomes overloaded.
- High tide in combination with low elevation.
- Pump failure.

PROBLEMS:

- Overflow of basements or even whole areas.
- Storm water overflows into sewage systems and overloads treatment plants.
- Contamination of reservoirs etc.

SOLUTION

To prevent problems caused by backflow in a system, backflow prevention in form of a check valve or a flap gate is installed.

The WaStop is an inline check valve which is closed by default. Wastop consist of two main components a valve body and a membrane. The valve body ensures that membrane has a perfectly matched surface enabling an airtight seal between the membrane and the valve body. The valve body seals against the pipe with a conical rubber seal allowing a good fit in a range of different diameter pipes.

The valve body is manufactured in stainless steel; AISI 304 or 316 the difference between the materials being 2-3% molybdenum improving 316s resistance to chlorides such as seawater, hence the popular name 'marine grade'.

The material of the membrane is either a special blend Silicone MVQ or a polyether based Polyurethane, smaller dimension WaStops are made in Silicone which has a high resistance to various chemicals and temperature variations. The larger dimension WaStops are made in polyurethane with high mechanical properties, giving the membrane high resistance to wear and tear.

Both membrane materials having high elasticity, meaning they will return to its initial shape and size when the forces deforming the membrane are removed. Hence the membrane is referred to as the 'memory' membrane. The membranes have been tested and showed no change in properties after 150 000 cycles (opening/closing).
The membrane is delivered as standard in three different shore hardness ranging from 35-80 SH. The softer membrane has a lower opening pressure but can't withstand as high backpressure, while the harder membrane has a higher opening pressure and is able to handle more backpressure. The application dictates which hardness to choose.

TECHNICAL ASPECTS

Important technical aspects deciding on which backflow prevention to use includes opening pressure and head loss.

OPENING PRESSURE

Since the WaStop is closed by default it operates with certain opening- and closing pressures. The difference between opening and closing pressure creates a pulsating effect, by rapidly changing the fluid velocity in the pipe it self-cleanses both the valve itself and the system.

Both opening pressure and head loss is both defined as Δh in fig.1. The difference being that the opening pressure refers to when there is no flow through the valve, and head loss is the pressure loss when there is a flow through the valve.

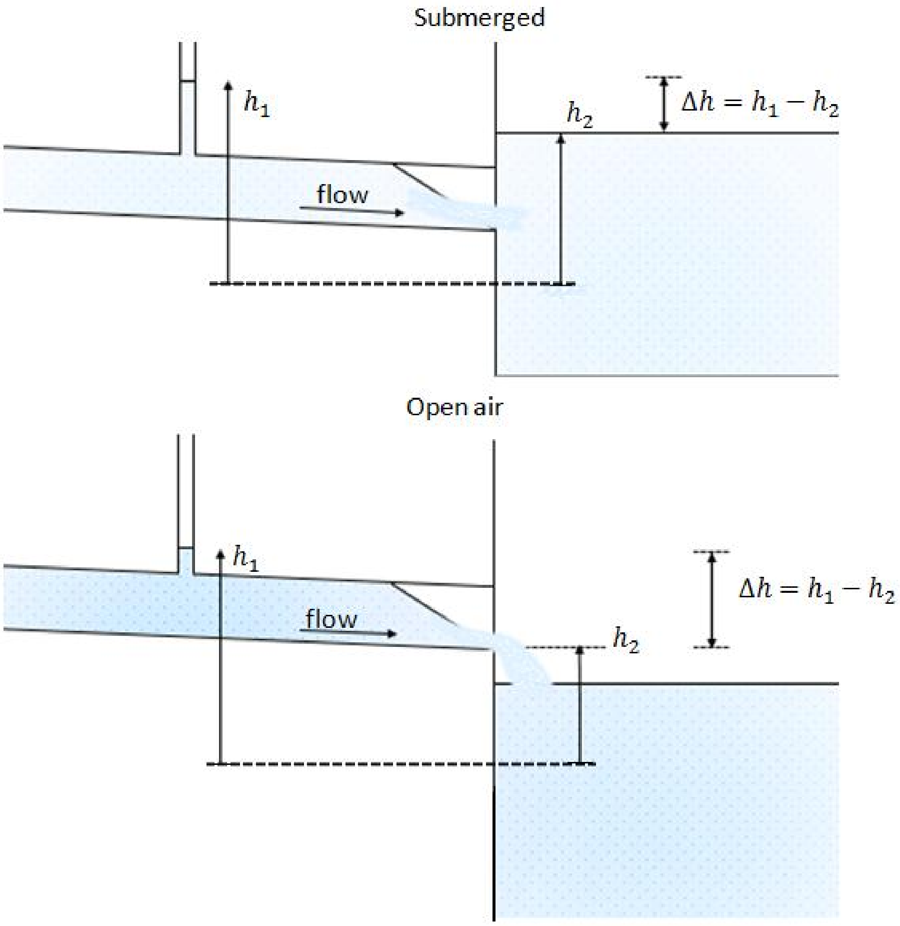

FIG. 1 OPENING PRESSURE AND HEAD LOSS DEFINITION.

PRESSURE LOSS

Pressure loss in a pipe system is calculated as the sum of major losses associated with energy loss per length of pipe and minor loss associated with bends, fittings, valves etc. Minor losses are estimated as:

$$\Delta p_{f,minor_L} = \frac{K_L \rho V^2}{2} = \rho g h_{L,minor} \Rightarrow h_{l,minor} = K_L \frac{V^2}{2g}$$

$\Delta p_{f,minor_L}: Pressure\ loss\ minor [Pa]$
$h_{l,minor}: Headloss\ (minor) [m_{H_2O}]$
$K_L: Loss\ coefficient\ [-]$
$V: Velocity\ in\ pipe\ \left[\frac{m}{s}\right]$
$g: 9.81\ \left[\frac{m}{s^2}\right]$

The total head loss of a system being:

$$h_L = \left(\frac{fL}{D} + \sum K_L\right)\left(\frac{V^2}{2g}\right)$$

$f\ : Friction\ factor\ [-]$
$L: Length\ of\ pipe\ [m]$
$D: Diameter\ of\ pipe\ [m]$

Since the hydraulic area of the WaStop depends on the flow through the valve, K_L depends on the fluid velocity in the pipe. The amount of throttling introduced by a check valve in the system determines the hydraulic efficiency of the valve.

From fig.6-11 (Appendix A). It is apparent that the loss coefficients are lower when the outlet is submerged compared to the open air discharge. An explanation is that the density of the membrane is only slightly higher than the density of water. Hence the apparent immersed weight of a membrane with the volume 0.1 m^3 and mass 130kg is only 30 kg submerged in water. Therefore the membrane opens more when submerged, i.e., larger hydraulic area meaning a lower head loss.

$$\Delta h_{submerged} < \Delta h_{openair}\ [mmH_2O]$$

METHODS OF ESTIMATING HEAD LOSS

There are several methods of estimating head loss. The method in this paper uses the resistance coefficient K_L. For all pipe fittings head loss are close to being proportional to the velocity head $\left(\frac{v^2}{2g}\right)$. As a result there are a few methods aimed at finding the correct multiplier for the velocity head term, such as the K_L and the *equivalent length method*. As the name suggests when using the equivalent length method one tries to convert the minor losses to an equivalent length of pipe which would give the same head loss as the fitting.

$$h_L = f\left(\frac{L}{D} + \sum \frac{L_e}{D}\right)\left(\frac{V^2}{2g}\right)$$

$L_e: Equivalen\ length\ [m]$

A method not based on finding a multiplier for the velocity head and mainly used for valves is the C_v method. By definition the valve flow coefficient $C_v = 1$ when a pressure of 1 psi causes flow of 1 US gallon per minute of water a $60°\ F$ through the valve.

$$Q = C_v\sqrt{\frac{\Delta P}{SG}}$$

This is a dimensional formula and the dimension must be in the following units

$Q: volumetric\ flow\ [GPM]$
$\Delta P: pressure\ drop\ [psi]$
$SG: Specific\ gravity\ of\ liquid\ relative\ to\ water\ at\ 60°F$

The European equivalent being A_V of a different magnitude with parameters in SI units.
In order to convert between K_L and C_v values we need to re-arrange equations and with the relation $\Delta P = \rho g h$ bring them to similar form, an exercise yielding the result:

$$C_v = 29.9 \cdot \frac{D^2}{\sqrt{K_L}}$$

$D: Diameter\ [inches]$

CASE STUDY OF PIPE SYSTEM WITH AND WITHOUT A WASTOP DN600 (24''),

A comparison of the total head loss (major + minor) of a system with 100 m (330') concrete pipe discharging into a slow moving lake, with and without a WaStop.

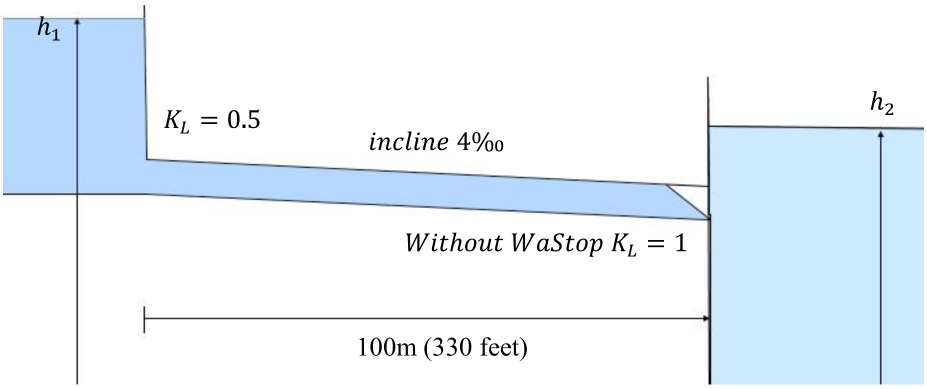

FIG. 2 PIPE SYSTEM DN600

ASSUMPTIONS:

- Pipe roughness $k = 2$ ($\epsilon = \frac{2}{600}$), pipe diameter 600mm (24")
- Discharge submerged, all the velocity potential is lost; $K_L = 1$ (without a Wastop)
- Inlet to the piping system $K_L = 0.5$
- K_L values for the given flow rates for the outlet with a WaStop from a test done at the Utah State University Water Researched Laboratory.
- Incline 4 ‰ (=0.4%)

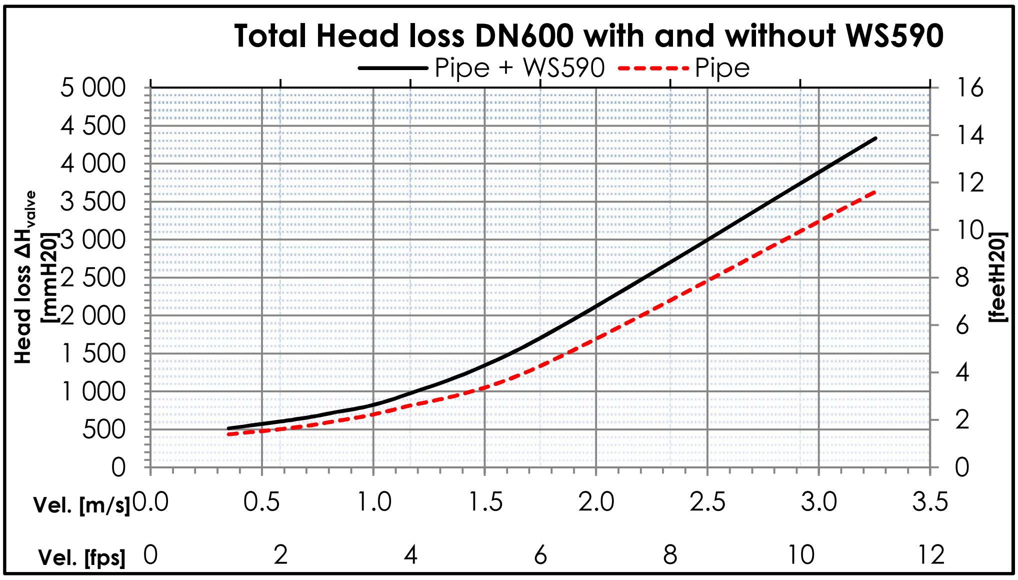

FIG. 3 TOTAL HEAD LOSS PIPE SYSTEM (FIG. 4) WITH AND WITHOUT WASTOP 590

INTERPRETING HEAD LOSS DATA

Comparing head loss data is difficult since the test procedure is rarely presented and there are multiple ways of altering data. However, the test results shown below were conducted in the same facility with the same reference points etc. are comparable. The test result shows that the WaStop has 65% lower head loss than a competing inline check valve at flow (2m/s). Both valves were tested in the same open air scenario.

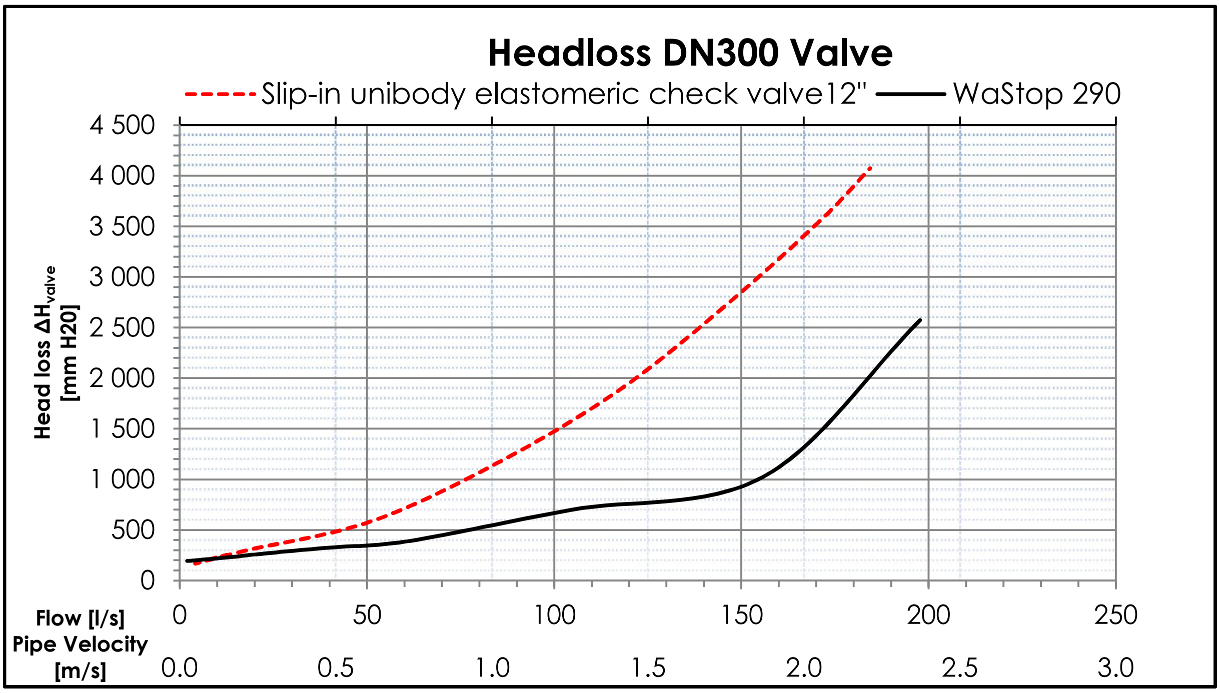

FIG. 4 HEAD LOSS COMPARISION BETWEEN A COMPETING INLINE CHECKVALVE AND THE WASTOP (SI-UNITS).

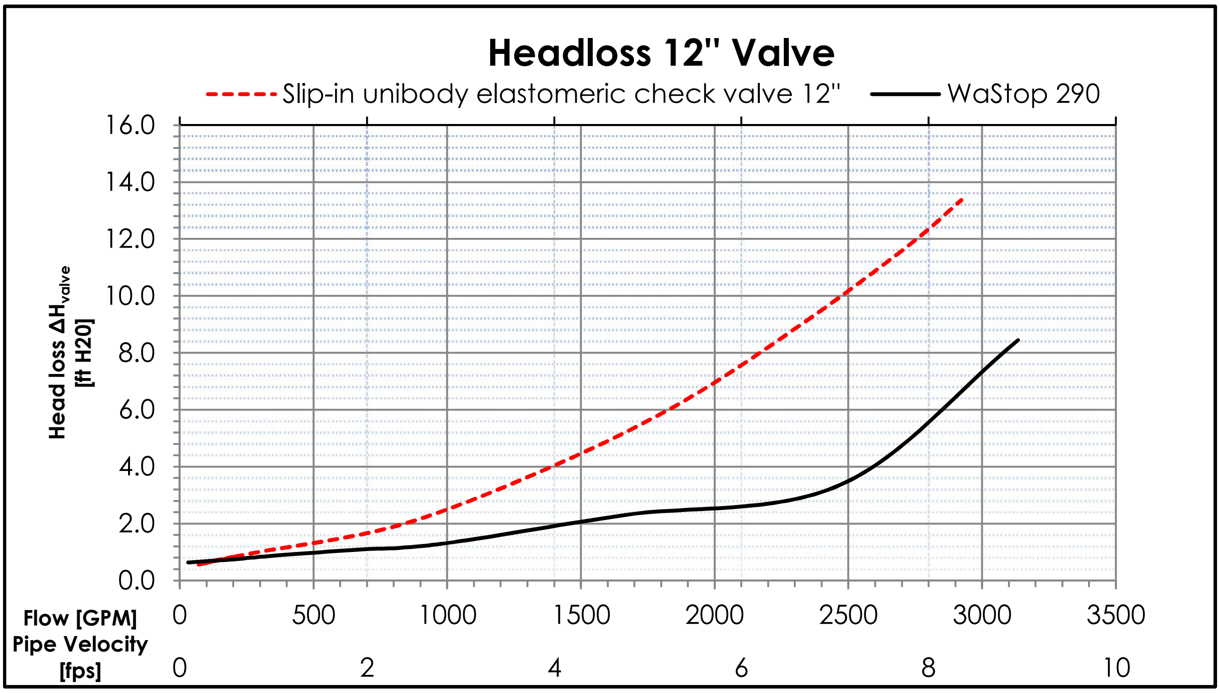

FIG. 5 HEAD LOSS COMPARISION BETWEEN A COMPETING INLINE CHECKVALVE AND THE WASTOP (US-UNITS)

CONCLUSION

The material choices in the design of a check valve are of high importance. The valve body needs to be rigid allowing a good seal between the membrane and the body, but also thin to not decrease the hydraulic area of the pipe more than necessary. The membrane needs to be elastic to regain its shape after many deformation cycles and still resistant to chemicals and wear and tear. The geometry of the membrane should allow flow with minimum head loss in one direction and be able to withstand high backpressures in the other direction. When comparing head loss data one need to make sure first of all that the data is comparable. That the same or similar test setup and procedure was used and datum points are the same.

Furthermore the head loss data presented in this paper is the total head loss for an outlet including a WaStop. In some situations as an example a submerged discharge, before the addition of a WaStop, the outlet has a loss coefficient equal to one. Hence the additional head loss introduced by the WaStop would be:

$$K_{L\_added} = K_{L,Wastop} - 1.$$

Same reasoning applies to all inlets/outlets already including some head loss before the addition of a Wastop, warranting some consideration before choosing a product preventing reverse flow.

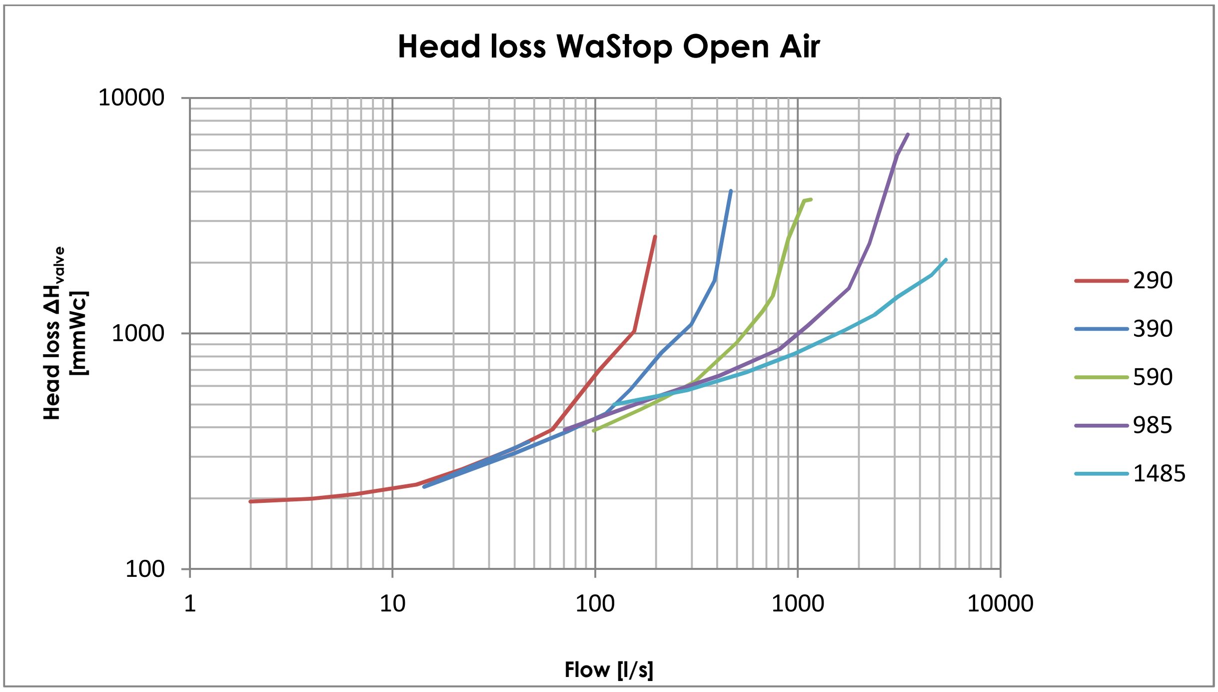

FIG. 6 OPEN AIR HEAD LOSS

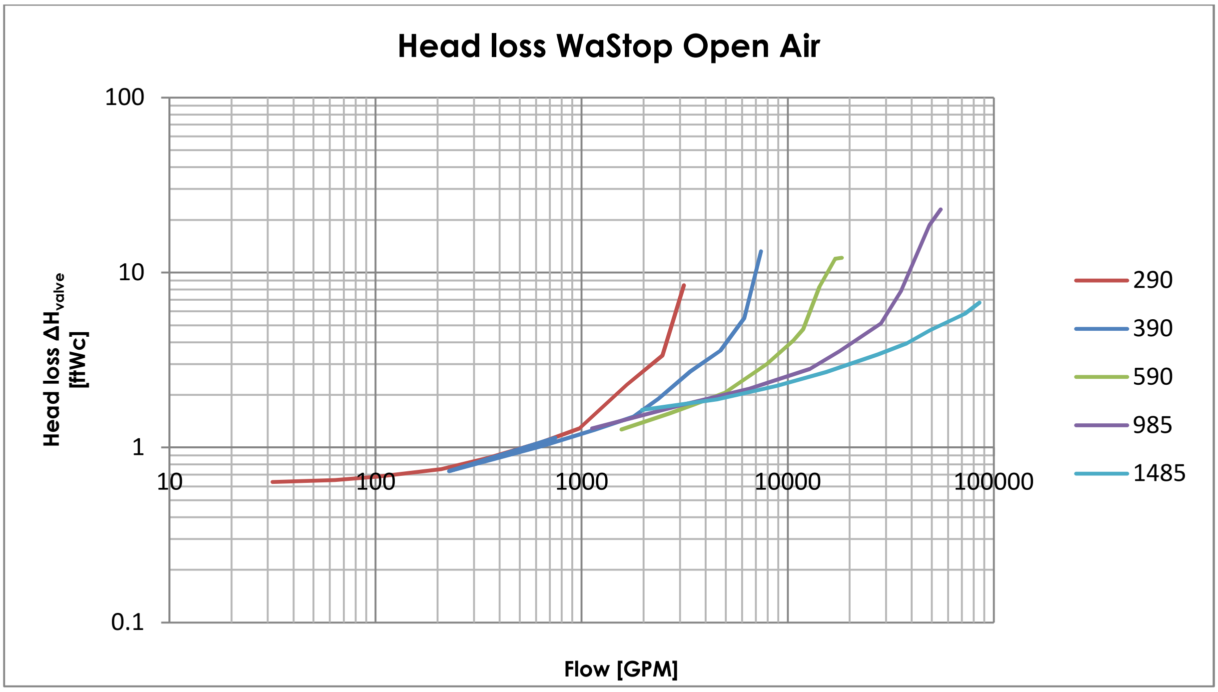

FIG. 7 OPEN AIR HEAD LOSS (US)

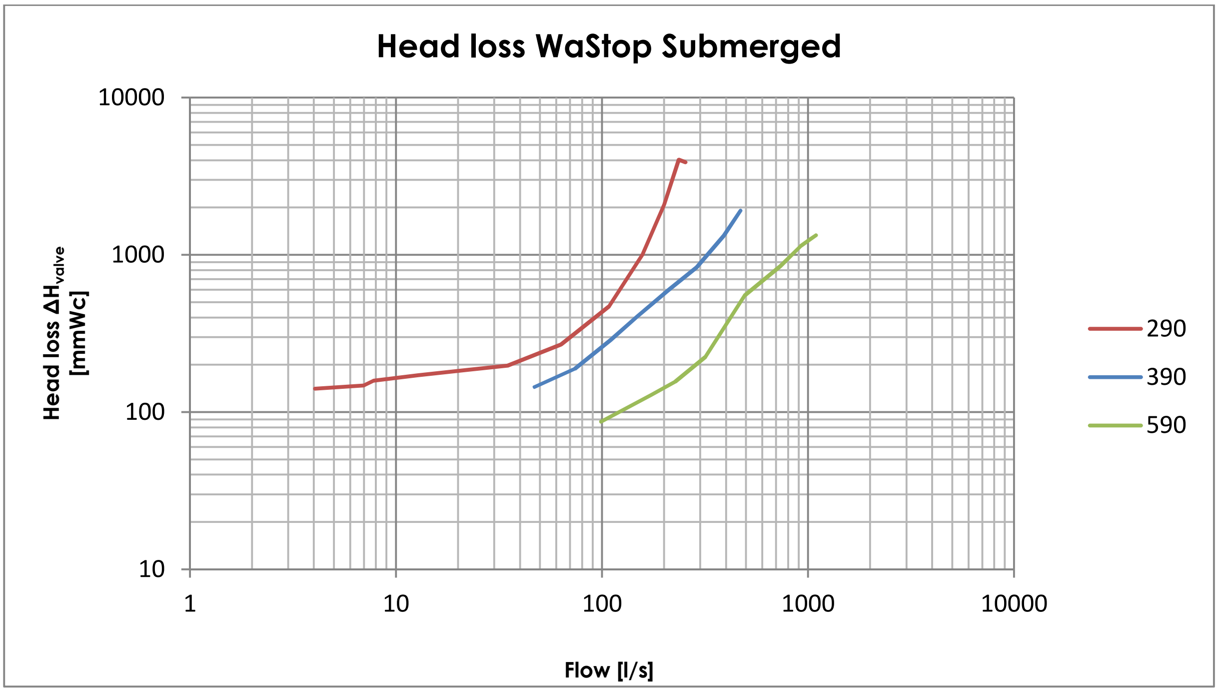

FIG. 8 SUBMERGED HEAD LOSS

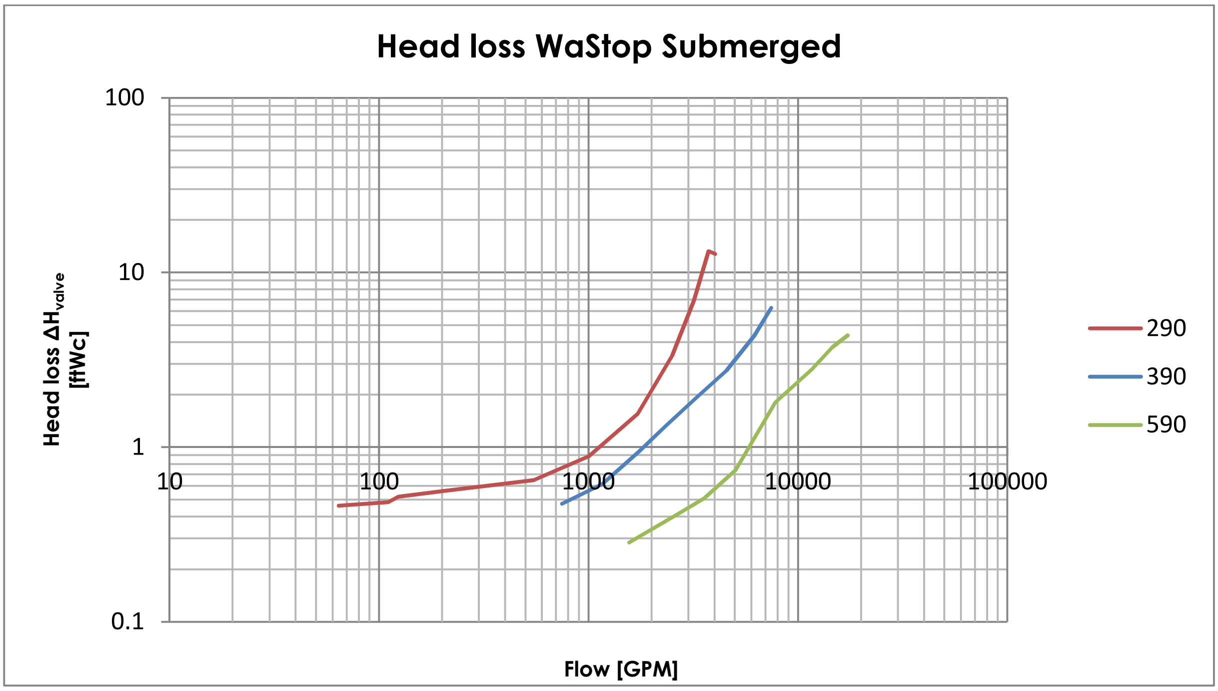

FIG. 9 SUBMERGED HEAD LOSS (US)

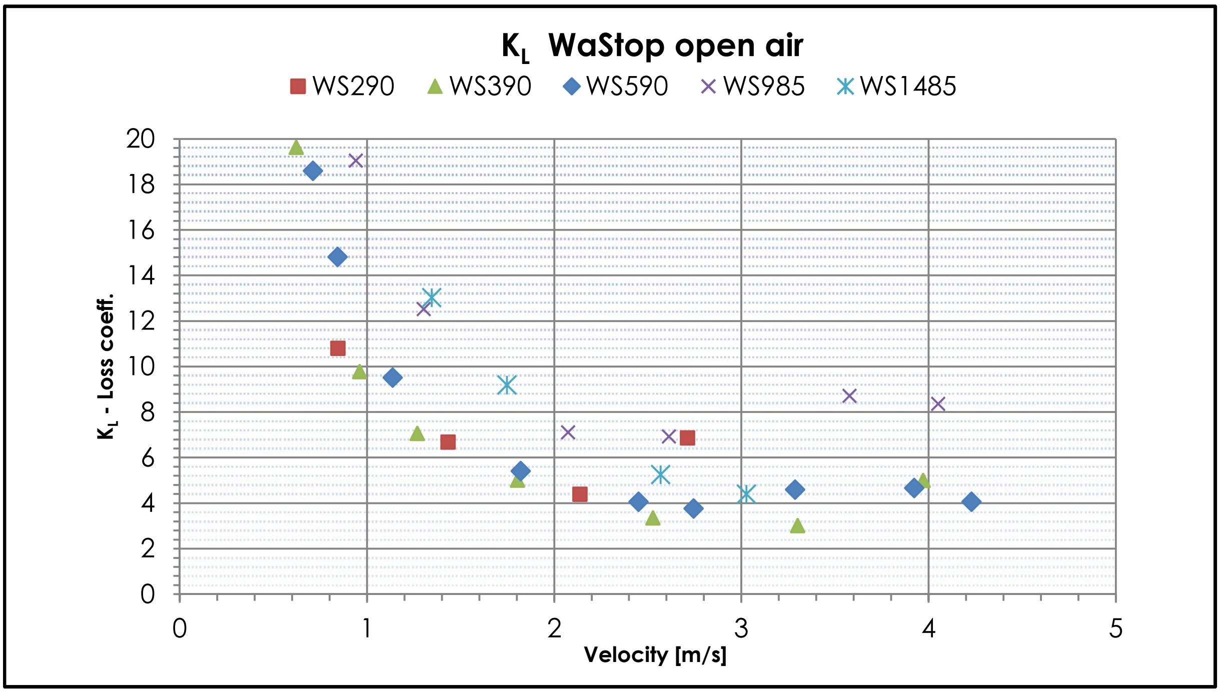

FIG. 10 K_L WASTOP OPEN AIR

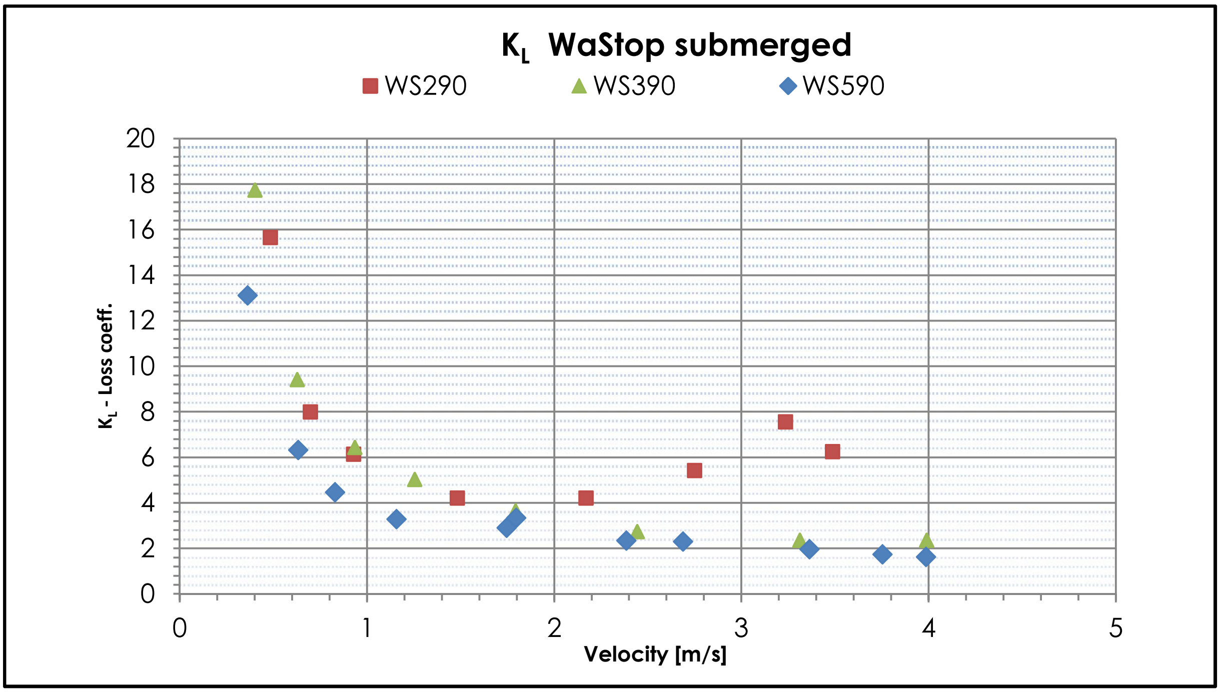

FIG. 11 K_L WASTOP SUBMERGED