Spring 2013

Multiphase Screen Development

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Abstract
This honors thesis research project was the study and development of a compact separation device for the oil and gas industry involving a multiphase cylindrical screen filter. Cylindrical screens can be used for solids removal in multiphase flow in upstream oil and gas applications. This study focused on cylindrical wire-wrap screen test unit design and performance characterization to determine volumetric flow rate and pressure drop correlations.

The project goals were met with research, test unit design, CFD modeling, calculations, and physical testing. The comprehensive testing will take place during the summer of 2013 and is planned to consist of building the designed flowloop and housing and using high capacity pumps to achieve higher flow rates. Multiphase testing will be performed with water, air, and sand particles and flow and pressure effects will be evaluated for solids filtering over time.

Keywords
separation device, oil and gas industry, multiphase cylindrical screen filter

Disciplines
Mechanical Engineering

Comments
Project Mentor: Hank Rawlins, Ph.D., Technology Director, eProcess Technologies; Project Advisor: David Bunnell, Ph.D., General Engineering Department, Montana Tech.

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Multiphase Screen Development
Honors Thesis Research, Fall 2012 and Spring 2013

Chris Tarrant
General Engineering - Mechanical
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Introduction

This honors thesis research project is the study and development of a compact separation device for the oil and gas industry involving a multiphase cylindrical screen filter. Cylindrical screens can be used for solids removal in multiphase flow in upstream oil and gas applications. This study focuses on cylindrical wire-wrap screen test unit design and performance characterization to determine volumetric flow rate and pressure drop correlations.

Research was conducted for the topic of screen types, behavior of multiphase flow, multiphase screen performance, and testing techniques. Next screens were selected for purchase from manufacturers and a test unit and flow loop were designed for testing screens at the eProcess Technologies laboratory. Computational Fluid Dynamics (CFD) software was used to model the screen and measure pressure drop for water or methane flow according to different screen geometries. Mechanistic equations were used to model the predominant flow phenomena for calculating the results. Initial testing was conducted using the physical screens and a basic flow loop set up. Figure 1 shows water exiting the screen during flow testing.

![Figure 1: Screen testing](image)

Background

Multiphase screens are used in a range of industrial applications. Screens come in various shapes and orientations, effecting hydraulic losses and performance characteristics for filtering solids. Screens are used for separation applications in food processing, mineral processing, and the petroleum industry among many others. The petroleum industry utilizes screens in both surface and subsurface applications for multiphase sand removal. Screens can be used for wells with sand control problems to prevent solids from becoming produced with the hydrocarbons by separating out the sand particles. Often in these applications multiphase describes the three-phase flow of hydrocarbons, water, and sand.

This project involves the development of a component for a post fracturing flowback surface system. A cylindrical screen will be utilized at the wellhead as an in-line separation device to protect equipment from produced sand during well flowback testing. Solids in the flow can lead to various problems such as wear and the erosion of the system’s components.

This screen will be used for relatively low pressures of under 100 psi. Concerns of screen performance, lifetime, and prolonged effectiveness are common in screen selection and design. An understanding of screen performance can lead to reaching maximum oil production and minimal solids production [1]. This study involves the evaluation of screen performance regarding hydraulic losses, indicated as pressure differential for various flow rates through the screen. Additionally plugging, screening ability and retained flow will be studied.
Requirements

The design requirements and constraints are shown below for both the test unit and screens.

Test unit:
- Instrumentation to monitor flow rate and pressure drop across the screen
- Housing must hold screens of 1 to 2 m in length
- Accessibility to the inside of housing to change out screens
- Screens must seal at both ends
- All parts selected for low cost

Screens:
- Screen 3" nominal diameter, or smallest possible
- Screening length of 1 meter (39") plus ends
- NPT end fittings
- Screen constructed of 304 stainless steel
- Screen mesh: one screen at 150 micron opening (100 mesh), one screen at 300 micron opening (48/50 mesh)
- Wedge wire screen construction
- Axially-aligned screen slot openings
- Flow pattern of inside to outside

Approach

The Fall 2012 semester consisted of reviewing technical papers, designing a test unit, and generating a computer model and running simulations with CFD. The Spring 2013 semester involved calculating results mechanistically and comparing the results with the experimental data from laboratory testing. This research focuses primarily on screen performance and characterizing pressure differential for various geometries, determined by screen opening size and overall length.

Research

Research was conducted to learn about common screen types, behavior of multiphase flow, screen performance evaluation, and testing procedures. Technical papers were reviewed from sources including the Society of Petroleum Engineers (SPE), Journal of Mass and Heat Transfer, and Journal of Fluids Engineering. The documents discuss topics related to screen selection, performance, and hydraulic resistance characteristics. Additionally, flow loop and filter designs from eProcess Technologies Malaysia were reviewed to gather ideas for designing the test unit.

Screen Types

Screens come in different types with variations in construction and orientation. Oil and gas industry screen applications generally utilize profile wire-wrap screens or premium, mesh-type screens. Mesh-type screens consist of wires woven together and can be plain or twill patterns in square, fourdrinier, or Dutch weaves [2]. Profile wire-wrap screens, commonly known as wedge wire or V-wire, consist of triangular-shaped rods. Different weaves and opening sizes produce different amounts of pressure drop due to hydraulic loss by resistance to flow.
Figure 2 shows examples of mesh-type and wire-wrap screens.

![Figure 2: Mesh-type (L) [2] and wire-wrap (R) [3] screens.](image)

The performance of woven-type and wire-wrap screens varies considerably. Wire-wrapped screens have a reputation of being susceptible to plugging [4]. Mesh-type screens are also better than wire-wrap screens for sand retention [5]. Screen opening orientation must be taken into consideration for design and testing of multiphase screens.

Wire-wrap screens have either radial or axial slot orientation and are designed for inside-to-outside or outside-to-inside flow patterns. Water wells commonly use cylindrical screens downhole to filter out solids from the formation. This screen is similar to a water well screen, except the screen orientation is designed for inside-to-outside flow, rather than for flow from outside-in. The screens are designed with the orientation of the wire toward the direction of flow, with the flat side of the wire facing the flow to filter out particles. Figure 3 shows the direction of flow approaching the screen.

![Figure 3: Wire-wrap screen orientation [6].](image)

**Multiphase Flow Behavior**

Multiphase flow is the incidence of two or more phases interacting with each other and moving as a fluid. Multiphase flow describes combinations of the solid, liquid, or gas phases. Multiphase flow is often water or brine with sand particles, containing oil and dissolved gas. Separation of the phases is often a concern for multiphase flow, for example when solids are not desired.

For separation applications several losses result from the screen, interrupting normal flow patterns. For screens, resistance of flow can be determined by viscous and inertial or kinetic loss components [7]. Viscous drag results from skin friction at the surface of the screen wires or from form drag. At high flow rates, viscous drag can be considered negligible. Inertial losses result from turbulent eddies and the losses from sudden enlargement and contraction of channel cross section of flow [8]. Boundary layer wall effects can also occur when the ratio of test chamber diameter to bed particle diameter is small.
This ratio must be large so these effects do not interfere with the resistance measurement through a packed bed or screen [9].

Darcy’s equation can be used to calculate pressure drop for porous material, in this case the screen or sandpack. Equations have been developed experimentally for correlating pressure drop and permeability across a flat, mesh-type screen for gas flow [10]. Darcy’s Law is shown in equation 1 below.

\[ Q = \frac{-kA}{\mu} \frac{\Delta P}{L} \]  

Equation 1

Where Q is flow rate, k is permeability of material, A is cross-sectional area, \( \mu \) is the dynamic viscosity of fluid, \( \Delta P \) is pressure differential, and L is length.

**Multiphase Screen Performance**

Screening particles from multiphase flow can lead to various phenomena that affect screen performance. The ultimate goal of screen filtering in petroleum applications is to achieve “acceptable solids retention with minimum loss in production” [5]. Screen performance can be evaluated by dirt-holding capacity and plugging tendency, which are impacted by particle size distribution [1].

The major concerns for screen performance are solids retention and screen plugging and permeability or retained flow capacity [11]. Solids retention is the measure of a screen’s ability to capture particles. Screen solids retention is found to be primarily due to the “population of particles larger than the screen openings” rather than due to the bridging of particles. The most particle retention occurs when screen the pore opening is smaller or equal to 2.5 times the median diameter of the median particle distribution (d_{50}), for somewhat uniform sand size in mesh-type screens [5]. Screen performance testing is often carried out to find the value of maximum solids production or retained screen permeability. “Master curves” or performance curves can be created from lab testing for retained screen permeability versus a ratio of effective formation size divided by screen pore opening [12]. The maximum acceptable amount of produced solids for oil wells is 0.12 \( \text{lbm ft}^2 \) or 0.15 \( \text{lbm ft}^2 \) for screen inflow area [5].

Effective solids retention should not be confused with plugging, and solids retention concerns are more relevant than plugging [5]. Nonetheless, the goal of screen performance is to prevent both plugging of the screen and sand production. Plugging can be said to occur when the pressure difference across the screen is more than twice as high as expected from the Darcy equation [4]. Plugging is less of a concern than pressure drop from buildup of sandpack [11].

Sand porosity and permeability refer to the particle’s properties of absorbing fluids or allowing fluids to pass through, respectively. Sand porosity and permeability properties are important because after time the sand is retained by the screen and the flow experiences resistance due to both the screen and due to the properties of the sandpack buildup. Sandpack buildup creates a pressure drop depending on the porosity of sand [11]. To understand screen behavior retained filter porosity/permeability must be examined [1]. For particle flow, erosion can is a concern [5]. More about the evaluation of sand buildup effects are discussed in Testing Methods. Sand porosity (\( \epsilon \)) can be equated using equation 2 with volume or area.

\[ \epsilon = \frac{V_{\text{air}}}{V_{\text{total}}} = \frac{A_{\text{air}}}{A_{\text{total}}} \]  

Equation 2
For experiments, when back-calculating for the permeability of a sand from a measured pressure drop across the sandpack and screen, certain effects must accounted for. Maintaining linear Darcy Flow and linear Forchheimer flow these in lab tests will simplify the results and ensure correct measuring [4].

Testing Methods

For evaluating different screen types and quantifying multiphase separation performance, several common testing procedures can be carried out in a laboratory. The objectives for performance testing are to characterize solids retention and hydraulic resistance of the screen, which is measured as a pressure drop.

The two most popular laboratory tests include the prepack test and slurry test. Prepack and slurry tests are two ways to analyze solids retention performance of screens in a laboratory setting. For the prepack test, sandpack is initially formed on the screen and water is flowed through at a set flow rate or pressure drop, and the solids that pass through the screen are collected. The slurry test involves pumping a slurry of less than 1% sand by volume through a screen at a given flow rate or pressure drop. It is most common to execute the slurry test by injecting sand at a constant rate into the flow upstream from a screen [5].

As solids build up behind a screen, the first layers of sand will have the convergence effects of the wire-wrap screen. If the test is continued, the pressure drop through the sandpack itself will govern local pressure gradient slope and pressure profiles. Sandpack a depth of 5 to 10 times the screen opening size is the transition for near-screen behavior and sandpack behavior for pressure drop. For sand layers under 5 to 10 times the screen opening size, the screen alone will primarily govern the pressure gradient. After sand depth of over 5 to 10 times the screen opening size has accumulated at the screen, the sandpack governs the pressure drop. Both situations should be tested to characterize screen performance. Tests should be run long enough for solids production to stop or stabilize [5].

A thin porous bed or section of packed bed containing glass particles can be used for simulating sandpack or screens. Studies of air flow resistance through crushed porous solids depends on factors of rate of fluid, viscosity and density of fluid, closeness and orientation of packing, and size, shape, and surface of particles [13]. For simulating a well’s flow behavior, two scenarios may be tested: low sand concentration and high sand concentration tests [11]. When installing instrumentation, suitable room must be left from the ends of the test section so pressure transducers do not pick up biased pressure data due to entrance and exit flow patterns [9].

Test Unit Design

A flow loop test unit will be assembled and used to evaluate the performance of several cylindrical screens, but is contingent upon funding. eProcess Technologies in Butte, MT supported this research and will provide a laboratory for testing.

Testing will occur in a high capacity pump flow loop configuration for evaluating screens, with a continuous flow through a test unit housing. The design of a flow loop and screen test unit housing, and screens were selected for purchase from manufacturers. Several preliminary flow loop designs were improved to create the final design. The major design challenges were to find clear PVC (polyvinylchloride) pipe and PVC fittings that are large enough for constructing a housing to surround
the screen, while selecting a screen that is small enough to fit within the housing. A parts list with costs was created for the test system design.

Housing and Flow Loop

The test unit design is comprised of 6” clear PVC housing to contain a screen of a 4” nominal size. The housing was designed to accommodate screens of various lengths from one to two meters, but initially for testing a screen of 1 m length. An extension will act to connect the flow to the screen inlet for screens of one meter length. The connections between the screen, attachments, and the housing are threaded NPT (national pipe thread). At the bottom of the screen a rubber pad will act as a seal. The unit was designed for an inside-to-outside flow pattern through the screen. All instrumentation is included in the design however specifications will depend on the particular test being run. A pressure differential measurement across the screen can be taken, using two independent pressure gauges or a differential gauge. Banjo quick-disconnect connections will be used throughout the test loop and to connect tubing with the test unit. An educator suction device will be used to manually inject the sand into the flow. Figure 4 shows the flow loop drawing.

![Figure 4: Test flow loop design](image)
The housing design and construction specifications are shown in Figure 5.

**Figure 5: Housing design for 6” test unit**

**Screen Selection**

To select screens to test, product research was conducted and manufacturers were contacted for fabrication options and limitations. AMACS/Amistco, Delta Screens, Alloy Screen Works, and Johnson Screens were contacted regarding the fabrication and cost of these screens. Screen manufacturer research included looking into reverse-flow water well screens and custom oil and gas cylindrical wire-wrap screens, which are constructed from wedge-wire. The screen construction was to be axial slot screen with the wedge-wire flat side facing inside, toward the direction of flow for inside to outside flow pattern.

Three 1 m long screens of nominal 4” ID were selected in 600, 300, and 150 micron sizes from the manufacturer Johnson Screens. The screen meets all the design requirements except the nominal size specification. For a relatively small diameter screen size (under 8”), structural integrity may become an issue because the welds tend to break when forming the screen. It was found that producing these screen constructions requires special machines and advanced techniques. For this reason, the 3” nominal size requirement could not be met, and instead the small possible diameter was chosen.
The screen is an internal rod construction with axial slots and for inside-to-outside flow pattern. A similar screen design is shown in Figure 6.

![Figure 6: Internal axial cylindrical screen design [14]](image)

Johnson Screens in Houston, Texas fabricated these screens custom for an internal diameter of 4 inches and with the correct orientation and an effective screen length of slightly less than one meter. Figure 7 displays the cylindrical screens.

![Figure 7: Three cylindrical screens used for testing](image)

**Cost and Parts**

The screen, housing, and test unit parts have been specified for the finalized design. Many of the parts needed for the design are already owned by eProcess Technologies and purchase will not be needed.

**CFD Model and Simulations**

FloEFD CFD software was used to simulate flow through a section of the housing-screen test unit assembly. Several initial models were created and refined to produce a model that would run efficiently with regards to computing power, time, and accurately. The major concerns for modeling involved reducing the Computational Domain region of study to analyze only a cross-section segment, and refining the computational mesh size to pick up the small features of the screen.
Due to computational resources and run time concerns, the FlowEFD CFD simulations were modeled using cross-sections of 1/20th and 1/40th of the overall one meter screen length. Appendix Figures 1, 2, and 3 show the CFD model dimensions. The results were then plotted on curves for pressure drop versus flow rate and cylindrical screen sizes of 600, 300, and 150 microns with water-only flow. The screen geometry was modeled in CFD and shown in Appendix Figures 5, with the wedge-wire features drawn according to actual dimensions [15]. The analyses were set up to run at fine resolution and at a manual gap size slightly smaller than the slot size, depending on the screen size. The gap sizes were specified to be 0.02”, 0.01”, and 0.005”, for the 600, 300, and 150 micron sizes, respectively. The model was set up with ambient initial conditions of 25 °C and 1 atm. The boundary conditions included an inlet volumetric flow rate at the inside of the screen. A solid cap was modeled at the end of the screen. The outlet boundary condition was an environmental pressure of 1 atm at the annulus area, between the outside of the screen end and the inside of the housing. The model is shown in Figure 8 below. Notice the inlet and outlet boundary conditions are shown with the red and blue arrows, respectively.

![Figure 8: CFD model with boundary conditions](image)

**CFD Results**

The run times for CFD simulations ranged from 5 minutes to 1 hour. The mesh indicates that the refinement of computation exceeds the resolution of the small slot sizes, indicating that calculations properly account for the screen’s resistance to flow. Figure 9 shows both 3D the mesh pattern and mesh on a pressure plot.

![Figure 9: Mesh displayed in CFD model](image)
The results show that FloEFD correctly analyzed the model, indicated by the discrete pressure changes observed around the interface of the screen and water. The small pressure changes are displayed in the pressure cut plot in Figure 10.

![Figure 10: Validating small model features](image)

The resulting pressure differential was determined for the 600 micron, 300 micron, and 150 micron size screens for flow rates at several points varying from 10 to 200 GPM.

The results from the model sections were than scaled to the full meter length of the screen. The relationship between pressure drop and area was determined using the Bernoulli Equation. Equation 3 shows the Bernoulli Equation.

\[
P_1 + \frac{1}{2} \rho V_1^2 + \rho gh_1 = P_2 + \frac{1}{2} \rho V_2^2 + \rho gh_2
\]

Equation 3

Simplifying the Bernoulli equation for the differential pressure yields the expression below in Equation 4.

\[
\Delta P = \frac{\rho}{2} \Delta \left( \frac{Q}{A} \right)^2
\]

Equation 4

Using Equation 4 the relationship for scaling the results from 1/20th of a 1 meter screen can be found below.

\[
A_{1m} = 20 \times A
\]

Where \(A_{1m}\) is the area for 1 meter length and A is the area of the 1/20th section. After substituting this into Equation 4 above, the resulting expression for the relationship between pressure drop, flow rate, and area if all other variables remain constant is shown below.

\[
\Delta P_{1m} = \Delta \left( \frac{Q}{A_{1m}/20} \right)^2
\]

So it can be noted that to magnify the results from the 1/20th section to a full meter length, the flow rate must be multiplied by 20 or the pressure drop be divided by 400.

The results from plotting the pressure drop for different flow rates is summarized in the graph in Figure 11 on the next page characterizing performance for various screen geometries of 1 meter lengths.
As expected, the smaller screen size yielded more resistance to flow, and consequently a higher pressure drop. The 150 micron screen produces a pressure drop that increases more rapidly than the other screen sizes with increasing flow rate. For the three screens, the behavior for pressure drop at various flow rates is positive and increasing. A graph similar to Figure 11, except with flow in BPD is shown in Appendix Figure 6.

Interaction between phases must be correctly modeled for multiphase flow. “Coupling scheme” refers to the primary and secondary phase’s flow dependency on each other and whether there is interaction between the phases in multiphase flow [16]. FlowEFD doesn’t have the capability of simulating multiphase separation because the program operates according to a one-way coupling scheme [17]. For effective two-phase separation modeling, the program must operate under a two-way or four-way coupling scheme.

FloEFD CFD simulations were also run for compressible methane flow for line pressure of 1000 psi. The methane was modeled as a real gas for two different scenarios for the model boundary conditions. The two models involved using independent flow rate and measuring pressure difference and also for an independent pressure difference and measuring flow rate. The results were converted from actual cubic feet per minute (ACFM) to standard (SCFM) and then to million standard cubic feet per day (MMSCFD). A compressibility factor of 0.95 was used for methane at the model conditions of 1000 psi and 50°F using charted data and converted to standard conditions and at compressibility factor of 1.0 [18].
The CFD methane simulation results are summarized for each of the three screens using the two methods in Figure 12.

![CFD Methane Simulations](image)

**Figure 12: CFD methane results for 1 m long screen**

**Mechanistic Calculations**

Mechanistic equation modeling of the predominant flow phenomena was carried out to approximate results from the hydraulic losses in terms of pressure differential for various flow rates. Uniform internal pressure, non-uniform internal pressure, head loss, per slot approach, and hydraulic resistance approaches were used to calculate the results. For equation modeling that included a coefficient of discharge ($C_d$) or loss factor ($k$), an average value for various hydraulic head of 0.65 was used for $C_d$. This value is an average of Bovey’s coefficients for rectangular shaped orifices of 1.26 cm$^2$ area, 10:1 ratio of sides to height, and oriented with the length horizontal [19]. This value was the closest among tabulated information for the flow scenario that could be found.

The uniform internal pressure approach involved rearranging the Energy Equation for differential pressure, and adding the entrance factor for head loss. The open and closed surface areas of the screen were summed and the flow situation was simplified into a blunt reduction in area. For this situation the flow experiences two changes. First the water fills and the screen, stops and changes direction, then the water flows through and exists the screen. The two velocities consist of the total flow rate divided by the total surface area and open surface area of the screen, indicating a symmetric radial path of flow.
Because the velocities of water flow are somewhat low this idealization is reasonable. The minor losses, velocity head, and pressure head were evaluated. Equation 5 shows the relationship derived from the Energy Equation for calculating the pressure drop assuming a uniform internal pressure. The theoretical expression for the hydraulic head (h) of the system is shown below.

\[ \Delta h_{\text{pressure}} = \Delta h_{\text{velocity}} + h_{\text{Losses}} \]

The relationship above can be expressed in variables as shown below in Equation 5.

\[ \Delta P = \frac{\rho}{2} \Delta \left( \frac{V^2}{2g} \right) + K \gamma * \left( \frac{V_{\text{screen}}^2}{2g} \right) \]

Equation 5

Where K is the loss coefficient, velocity is the change through the screen and \( V_{\text{screen}} \) is the velocity as the flow passes through the screen open area.

The non-uniform internal pressure method is the same approach as the uniform internal pressure approach however the screen was divided into ten discrete sections along the length. The centerline velocity of the water flow was correlated with the water escaping the screen, and furthermore the building pressure inside the screen. Since the centerline velocity changes from a maximum value at the entrance of the screen to a value of zero at the closure plate end of the screen, the pressure may increase along the same trend as decreasing centerline velocity. The pressure was assumed to increase linearly along the length of the screen. At each section the Energy Equation in Equation 5 was used to evaluate the pressure difference due to changes in area as well as minor losses in the screen for the that velocity through the screen.

A screen head loss equation from Chemical Engineering Handbook was also used to model the pressure difference. This equation can be used for various screen types. Equation 6 shows this screen head loss equation where the velocity is the approach velocity of the flow toward the screen, calculated used the total surface area of the screen.

\[ \Delta h = \frac{n}{C} \left( \frac{1-\alpha^2}{\alpha^2} \right) \left( \frac{V^2}{2g} \right) \]

Equation 6

Equation 6 shows the coefficient of discharge C, number of screen layers n, percent open screen area \( \alpha \), and approach velocity V.
For the per slot basis, Equation 5 was used without the head loss term to calculate the losses halfway between two of the axial wires based on area open or closed to flow. In this scenario the open and closed areas were calculated for one slot opening, from the cross section of the screen. The amount of pressure drop was reduced for the total area of the total number of slots for each screen based on the geometry.

The hydraulic resistance model involved accounting for the major losses in the screen due to fiction during flow along the length. Because of wall effects and zero velocity at the wall surface, interaction between the fluid and wall causes losses along the wall boundaries. These losses were modeled for both the length of the screen and the annulus space. To account for flow through any of these areas the average of the maximum value and zero velocity were taken when calculating both the head losses for the inside of the screen and the annulus space. The cross-sectional velocities were used for calculating the friction factor using the Swamee-Jain equation and pressure drop.

The results from these mechanistic calculations are shown in Figures 13 through 15 below and on the next page. The graphs show a range in flow rate in CFS from 0.1 to 2.0, which is about 1400 to 30,000 BPD.

![150 Micron Screen Mechanistic Calculations](image-url)

*Figure 13: 150 micron mechanistic approximations for 1 m screen*
Figure 14: 300 micron mechanistic approximations for 1 m screen

Figure 15: 600 micron mechanistic approximations for 1 m screen
The mechanistic approximation results for methane are included in the appendix. The methane flow was modeled as compressible flow; however, for velocities under about 0.3 Mach (335 ft/s) compressible flow behaves the very close to non-compressible flow such as for water [20]. The same equations for mechanistically modeling water flow were used for methane, with the exception of the loss coefficient value used. A coefficient of discharge was selected for the methane scenario from air duct tables for minor loss coefficients. These values were used for each grill ratio of open area to total surface area. Appendix Figure 7 displays the estimation of the minor loss coefficient using the data available for air duct grills. Appendix Figure 11 shows the methane comparison for the head loss equation and the CFD results. The screen head loss equation was selected for the methane mechanistic modeling because of its closeness to the actual testing results from the water tests.

**Initial Lab Testing**

Initial testing was performed at the eProcess Technologies laboratory. Conducting comprehensive testing is planned for summer of 2013 but is contingent on funding.

Three different screens were tested for slot opening sizes of 150, 300, and 600 micron. Screen area had to be reduced because high capacity pumps were not available for achieving noticeable pressure drop. Area was reduced to 3.8% of the total area for the 1 m long screens and the results were scaled up to represent values for the entire 1 meter long screens. The screen and insert for reducing the area internally are shown in Figure 16 below.

![Figure 16: Screen (bottom) and insert (top) for reducing effective screening area](image)

Inlet pressure and flow rate indicators were used to collect data. The screen was not set up with a housing chamber; rather the screen was placed inside a tank so that the water exiting the screen would be collected and recirculated. The inlet pressure gauge was zeroed to read differential pressure between the inlet and atmosphere.
The initial lab testing set up is shown in Figure 17 and Figure 18 with the components labeled and the direction of flow indicated.

Figure 17: Test setup in lab

Figure 18: Testing flow loop

The screen is shown with turbulent flow exiting the screen within a viewing chamber in Figure 19.

Figure 19: Flow exiting screen during testing
Figure 20 displays a close-up photo taken of the flow streams passing through the screen.

![Figure 20: Flow Exiting Screen](image)

**Testing Results**

The results from testing the screens are shown in the Figure 21. Because of the instrumentation and slight fluctuations in indicators, the results should not be considered accurate to within about 5%.

![Figure 21: Results from lab testing screens of 1 m](image)

Similar to the CFD simulation results, the testing results exhibits positive and increasing slope. The 150 micron screen experienced slight plugging from screening small particles of sand that existed in the system. This plugging is observed by the sharp increase in pressure at 1100 BPD flow rate for the 150 micron screen. Slight plugging was also observed in the 300 micron screen, which may have caused a small amount of build up in pressure. The plugging is shown in the plot in Figure 22 on the next page, where the 150 micron screen test data is shown for increasing and then decreasing flow rates during one test. Note the rapid increase in pressure as flow rate is increased and hysteresis in path as flow rate was increased and decreased.
Conclusions

The theoretical curve that best fit the data was the head loss Equation 6. The testing results are shown in Figure 23 for the three screens along with the theoretical results for the head loss equation with a $C_d$ value of 0.8. Appendix Figure 12 shows the curves with fit lines.
The head loss equation was found to produce the closest trend to the water testing data. Figure 24 shows the comparison for the test data and head loss equation for a coefficient of discharge of 0.8. This value is the fit best to the data and is reasonable since $C_d$ is usually around 0.6 for blunt area reductions and about 1.0 for nozzles [21].

The water-only results were fitted with a power curve. The coefficients of correlation for the test data show values near unity, indicating that the data consistently followed a power trend. The CFD trends were found to increase with the same power as the theoretical curves. The curves for the mechanistic results, CFD, and testing results all have the same general shape of positive and increasing slope. As flow rate increases the pressure differential was found to increase, but by larger amounts. The coefficients for the test data and the theoretical results compare closely, however the test data exponent had a higher value. The shapes for all the testing, theoretical, and modeling results compare closely, increasing exponentially with a power curve shape and this data was fit to power curve lines. The CFD results were found to be at higher pressures than the testing and theoretical results. Screens of finer slot opening sizes were found to cause comparatively larger pressure differential values. Because of its closeness to the actual test data, the head loss equation with a $C_d$ of 0.8 can be used to predict flow rate for the screens with relative accuracy.

The project goals were met with research, test unit design, CFD modeling, calculations, and physical testing. The comprehensive testing will take place during the summer of 2013 and is planned to consist of building the designed flowloop and housing and using high capacity pumps to achieve higher flow rates. Multiphase testing will be performed with water, air, and sand particles and flow and pressure effects will be evaluated for solids filtering over time.

Thanks to their assistance, this research was carried out with supervision and guidance from eProcess Technologies' Technology Director, Hank Rawlins, PhD and Montana Tech General Engineering professor, David Bunnell, PhD.
References


Appendix

Appendix Figure 1: 150 Micron CFD Model Dimensions

Appendix Figure 2: 300 Micron CFD Model Dimensions
Appendix Figure 3: 600 Micron CFD Model Dimensions

Modeling Dimensions:
- ID Housing = 6.031"
- OD Housing = 8.625"
- ID Screen = 4.0"

Screen:
- Open Area = 6.36 ln2
- Percent open area = 27.5%
- Height of wire = 0.1"
- Width of wire screening face = 0.083"
- Actual spacing = 0.0243"
- Flow Length = 1/20th of 1 m = 1.8668"
- Depth of BC pads
- Inlet = Outlet = 0.05"

Appendix Figure 4: Flow trajectory pattern of CFD model: 600 micron screen and 200 GPM

Appendix Figure 5: CFD Model Screen Images

150 μm (0.006”) 1/40th of 1 m long
300 μm (0.012”) 1/20th of 1 m long
600 μm (0.024”) 1/20th of 1 m long
Appendix Figure 6: CFD Results showing flow in BPD

![CFD Simulation Results for Water](image)

Figure 7: Air Flow Minor Loss Coefficient Estimation

<table>
<thead>
<tr>
<th>Ratio of free to total surface area</th>
<th>Minor Loss Coefficient</th>
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<tr>
<td>Grilles, 0.7 ratio free area to total surface</td>
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<tr>
<td>Grilles, 0.6 ratio free area to total surface</td>
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<td>Grilles, 0.5 ratio free area to total surface</td>
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<tr>
<td>Grilles, 0.4 ratio free area to total surface</td>
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<td>Grilles, 0.3 ratio free area to total surface</td>
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<tr>
<td>Grilles, 0.2 ratio free area to total surface</td>
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Input

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<tr>
<th>Screen Size</th>
<th>Coefficient</th>
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<tr>
<td>150 micron screen</td>
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<tr>
<td>300 micron</td>
<td>0.163</td>
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<tr>
<td>600 micron</td>
<td>0.278</td>
</tr>
</tbody>
</table>

Minor Loss Data Extrapolation

Series1

- Power (Series1)
Appendix Figure 8: 150 Micron Screen Comparison for 1 m
Appendix Figure 9: 300 Micron Screen Comparison for 1 m
Appendix Figure 10: 600 Micron Screen Comparison for 1 m

Appendix Figure 11: Methane Curve Comparison for 1 m
Appendix Figure 12: Results comparison with curve fits