Keep on moving

Dr. John Smart III, Inline Services Inc., USA, talks about calculating velocity for solid particle movement in oil and gas pipelines.

In oil and gas production and pipelines, solids such as sand, sediment and black powder can be a major problem. They can cause partial pipe blockage, erosion of elbows and other points of impingement in the flow stream as well as damage to compressors and gas turbines. Resultant fouling of the pipe could lead to stuck pigs and prevention of inspection by ILI pigs.

The calculated velocity to move solids in water, oil, and gas is presented in this paper based on a hydraulic model. The entrainment velocity is a function of fluid properties, particle shape and density, and pipe diameter. When the fluid velocity is less than required to move particles, they will accumulate in a bed for which the steady state bed height can be estimated. Higher subsequent velocities can result in the movement of large quantities of solids, which can plug filters and damage downstream equipment. Pigging to clean a pipeline may also loosen solids adhering to a pipe wall and result in large quantities of

Figure 1. Black powder from a natural gas pipeline.

solids travelling long distances down a pipeline.

The model used to calculate the velocity required to sweep solids through horizontal pipelines by fluid drag has been developed by Wicks, who confirmed the model using movement of sand in oil and water piping. Field results indicate that the model is excellent in predicting the onset of particle movement in real pipelines, and was used to calculate the solid particle movement velocities presented here. In the following sections, this correlation was used to predict what velocity is required under various conditions such as sand in water, iron compounds such as iron oxides, iron sulfide, and iron carbonate in crude, and black powder in natural gas.

Figure 1 shows a pit cleaning pig with specially designed brushes removing black powder from a gas line. Particle size is typically in the range of sub-micron up to approximately 100 microns.

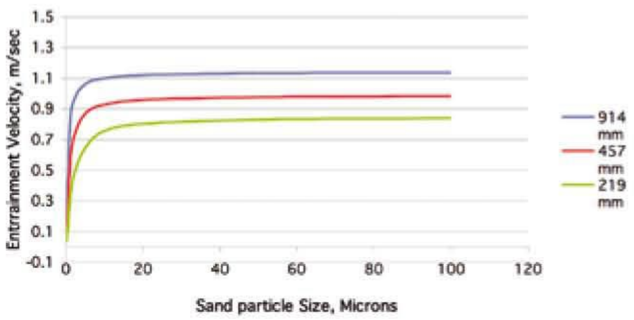

Figure 2. Fluid movement velocity for sand in water vs. particle size (microns) for various pipe sizes.

Several factors must then be applied to the calculated results:

- The results are for solids in liquids and dry solids in gas pipelines. Gas pipelines containing liquids such as compressor oil or glycol require higher velocities.
- Calculation results are for dilute concentrations of solids where the viscous forces from one particle do not effect others.
- The particle diameter used in the analysis is the effective particle diameter, given by a shape factor times the characteristic diameter such as the average sieve size. Shape factor is the particle perimeter divided by pi; and is in the range of 1.5-2 for most pipeline solids.
- Results are for horizontal pipelines, with an additional factor of 10-15% required to be able to push particles uphill in real pipelines.

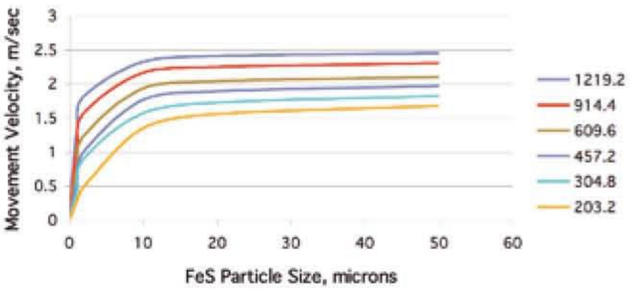

Figure 3. Velocity to move iron sulfide in 400 API oil vs. particle size and pipe diameter (mm).

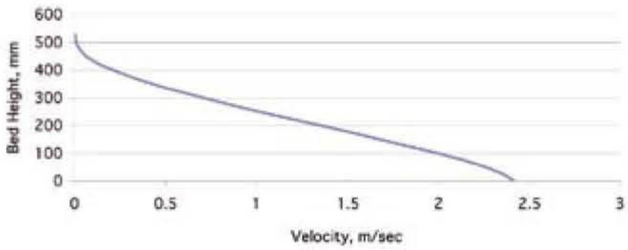

Figure 4. Steady state sediment bed height in a 609 mm (24 in.) pipeline carrying no.2 diesel fuel at 18 °C.

- Vertical pipe sections such as risers should use Stokes Law to determine the velocity.

Movement velocities of solids in pipelines

Water velocity to move sand

Figure 2 shows the movement velocity for quartz sand in water at 60 °F. The velocity required to move sand is from 0.8 to 1.1 m/sec in pipe from 8 in. (219 mm) to 36 in. (914 mm) diameter. An additional 10-15% needs to be added to the velocity shown to account for up-hill flow.

As can be seen, the movement velocity is higher for larger diameter pipes and falls rapidly when the particle size is below approximately 10 microns. For larger particles, the movement velocity increases only very slowly. This is an important number to know when pigging a pipeline, because if the sand is moving at a velocity greater than the particle movement velocity, it will not drop out in front of a pig and the line can be cleaned with little risk of sticking a pig.

Figure 5. Iron oxide sediment in a 508 mm pipeline. The volume of sediment can be enormous and should be considered in pig cleaning operations.

Iron sulfide in 40 °API oil

Of more practical interest in the oil and gas industry, are the velocities shown in Figure 3. The velocity for iron sulfide also approximates the velocity to move iron oxides and iron carbonate due to the closeness of their densities, ranging from 3.8 gms/cm^3 for iron carbonate, 4.82 for FeS, 5.1 for Fe_3O_4 and 5.24 for Fe_2O_3. A density of 4.82 gms/cm^3 was used in these calculations. Some pipeline operators report that most black powder is iron sulfide, while others report only iron oxide. Generally, black powder is a mix of iron compounds, sand, salt, weld slag, mineral scale, clays and other compounds. Older pipelines frequently contain weld rod stubs and other debris.

The higher velocity for iron compounds means that pipelines containing iron oxides and sulfides (black powder) will likely accumulate sediment deposits in the line. The height of the sediment bed under steady state flow can also be estimated using the flow model, and is shown in Figure 4 for a 24 in. pipeline containing No. 2 Diesel oil and iron sulfide. Note that this bed height is a steady state maximum that would only occur if there were very large quantities of solids in the pipeline.

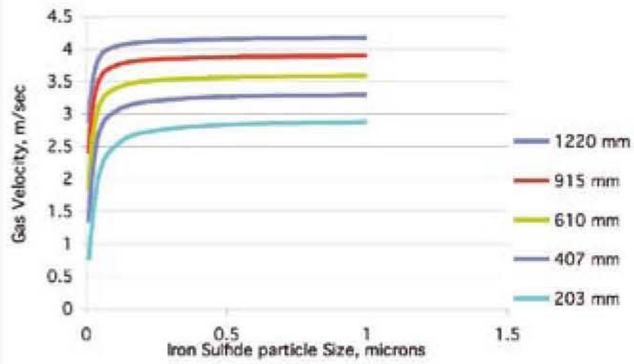

Figure 6. The effect of pipe size and particle size on the velocity to move iron sulfide particles in natural gas at 69 bar (1000 psi) pressure and 18 °C.

No. 2 diesel fuel at 18 °C

An example of sediment in a crude oil pipeline is shown in Figure 5, from a section of a 508 mm (20 in.) pipe. The accumulation of solids in a pipeline can be enormous, and can cause pigs to become stuck if the pigging procedure is not designed to clean the line gradually such as in progressive pigging, or by use of gel pigs to suspend the sediment ahead of the pigs. Estimating the depth of solids contained in the pipe shown in Figure 5 as 12.6 mm (½ in.) deep in a 508 mm diameter pipeline, the volume of solids is approximately 0.385 m^3/km, weighing over 1125 kg per km as iron oxides or sulfides. If the depth of the deposit were 25 mm, the weight of iron oxides/sulfides would be over 5060 kg/km. When this line was pigged for cleaning, 150 t of iron oxides and sulfides were removed from a section 100 km in length. Collection and disposal of these solids can be a major problem. Deposits of sediment will be more serious on uphill sections of line.

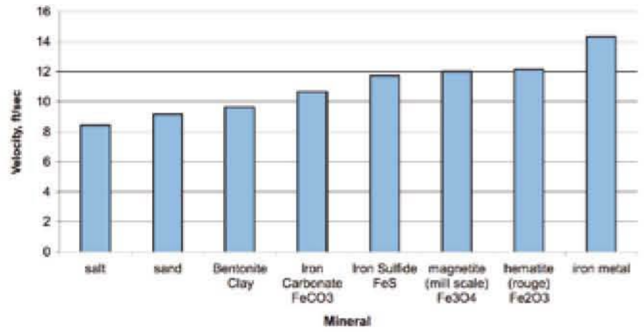

Figure 7. Velocity to move various black powder minerals in a 610 mm pipeline at 69 bar pressure and 18 °c.

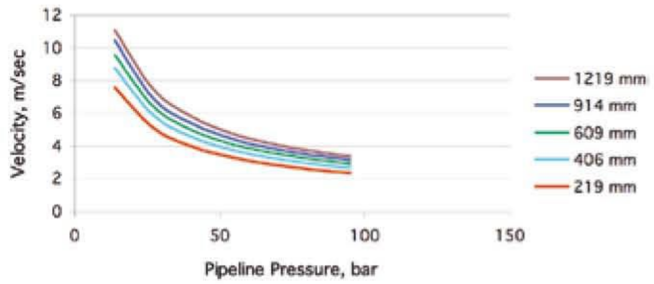

Figure 8. Velocity to move 1 micron iron sulfide particles at 18 °C vs. pipe diameter and pressure.

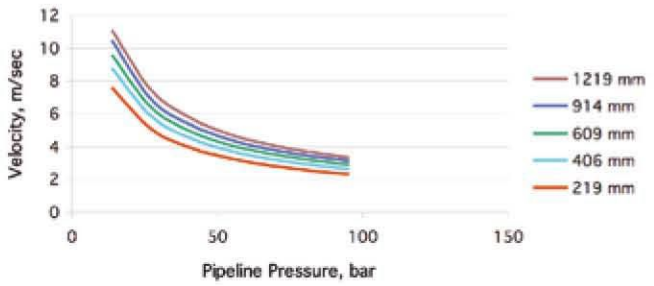

Figure 9. Flowrate of natural gas required to move Iron Sulfide solids in a 1219 mm (48 in.) natural gas pipeline vs. line pressure. Note that as the pressure decreases, the flowrate required to move solids also is reduced. This means that once black powder is set in motion, it will continue to move until it reaches a compressor statio or the flowrate of gas is reduced.

Black powder movement in natural gas

Black powder has become a major operating problem in many natural gas pipelines, threatening the status of natural gas as a 'clean' fuel. Solids can include produced sand, corrosion products such as iron carbonate, iron oxides and iron sulfide, metallic iron, weld spatter, salt, asphaltenes and scale. The term 'black powder' is often used to describe this combination of solids in natural gas pipelines. Black powder is a good generic name for these solids, as they don't seem to have a lot in common other than the mix being black. In the author's experience, black powder contains a mixture of iron oxides, iron sulfide, metallic iron particles, sand, silt, clay, mineral scale, weld slag and weld rod stubs left over from construction. Magnetite, or mill scale, is always black, but hematite can be either black or red (rouge) depending on its particle size. Mineral scale can also be present from produced water, such as calcium and magnesium carbonate, calcium sulfate, barium sulfate, strontium sulfate, and salt. In addition to these common materials, polonium is found in some Southern UK North Sea Gas Fields. Barium and polonium are NORM compounds.

Figure 6 shows the velocity to move black powder in natural gas pipelines, operating under the conditions of 18 °C and 69 bar. Gas velocity required to move black powder under these conditions is 2.8 m/sec in 219 mm pipe to 4.2 m/sec in 1219 mm pipe. Natural gas pipelines can vary in their flow velocity depending on the season, and may cycle above and below this number. If the pipeline were operated in a corrosive condition, large amounts of black powder could result that may possibly be delivered to customers, or, at the least, require substantial filtering capacity before compression or delivery.

These results explain why gas pipeline compressor stations need to have filters installed in front of compressors, to catch black powder coming from upstream gas flow. Pipeline operators report that as black powder is transported down a pipeline, it fractures and becomes very fine, with a size in the range of 1 micron or less. Extremely fine powder like this can pass through normal pipeline filters, requiring that sub-micron filters be used. They also report that extremely fine powder such as 1 micron can be tolerated by reciprocating compressors, but can damage turbine compressors, even with filters in place. The relative velocity to move other black powder minerals is given in Figure 7, under the same conditions of 69 bar pressure and 18 °C in a 610 mm natural gas pipeline.

Figure 8 shows that the velocity to transport iron sulfide black powder in natural gas increases due to lower gas density as the pressure in the line is reduced. Figure 9 shows that the flowrate of gas in the line is reduced as the pressure is reduced. This means that once black powder starts to move in a pipeline, it will continue to move until it comes to a compressor station or gas is removed from the line to lower the flowrate. If the flowrate increased, possibly due to seasonal demand for gas or increased use by a consumer, then the deposits of black powder can start in motion again.

Dry powder vs. real pipelines

The velocities shown in the above section assume that the black powder is contained in a horizontal pipeline and is dry, that is, there is no oil or other substance binding it to the pipe wall. It is well known that dry gas pipelines have more severe black powder problems than pipelines that contain compressor oil or other substances that cause the powder to adhere to the pipeline wall. Recent experiments to measure the velocity required to move black powder in a transmission gas pipeline indicate that the velocity required to 'blow out' sediment and debris from a series of river crossings was approximately twice of that calculated for the movement of dry black powder. The river crossings were horizontal directionally drilled to a depth of up to 80 m. Included in the debris collected were dry powder, oily powder, valve grease and weld rods.

When black powder movement is a problem in US gas pipelines, corrosion inhibitor has been injected into the line to successfully reduce the problem. Corrosion inhibitors are sticky compounds and will bind the powder particles to the side of the pipe, allowing the pipeline to operate to higher velocities without problems.

Conversations with pipeline operators reveal that when pipelines are cleaned for such purposes as ILI inspections or flow improvement, the result is initially a clean line. However, after some time, black powder is usually found coming down the line again even when the lines are dry and solids are not being generated by internal corrosion. Effective routine maintenance using aggressive pig designs will minimise the accumulation of Black Powder or other deposits. Inline specifies rehabilitation and maintenance cleaning programmes for debris problems in pipelines. WP

References

1. WICKS, M., "Transport of Solids at Low Concentration in Horizontal Pipelines" in Advances in Solid-Liquid Flow in Pipelines and its Applications, Edited by Iraj Zandi, Pergammon Press, New York, 1971 pg. 101-124).
2. BALDWIN, R., "Technical Assessment: "Black Powder" in the Gas Industry – Sources, Characteristics, and Treatment," Gas Machinery Research Council Report TA 97-4 May, 1998. Report available at www.gmrc.org/technology-reports.html Report 97-4.
3. WINTERS, R., "The Black Powder Problem in Gas Pipelines – An Industry Overview" Presented at the 14th Annual Pipeline Pigging, Integrity Assessment and Repair Conference, Houston, TX. Jan, 2002. sponsored by Clarion Technical Publications.
4. BALDWIN, R., "What is Black Powder? An Overview" presented at the Black Powder Forum, Feb. 17, 2006, Houston.
5. SMART, J., "Determining the Velocity Required to Keep Solids Moving in Pipelines" presented at The 19th Pipeline Pigging and Integrity Management Conference Houston, Texas, February, 2007.
6. SMART, J., "Movement of Black Powder in Gas Pipelines" The Journal of Pipeline Engineering Vol. 6 No. 1 (1st Qtr, 2007).
7. SMART, J., "Movement of Black Powder in Gas Pipelines" Pipeline and Gas Journal, October, 2007.
8. SMART, J., "Flow Velocity Required for Particle Movement in Oil and Gas Pipelines" Presented at The Symposium on Evaluation and Rehabilitation of Pipelines Prague, 20-24 October, 2008.