

20231008TranscriptChatGPT4-PumpWallErosion



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GPT-4



Hello Again - It is Sunday 2023/10/09 at 12:44 local time - I'd like to take up the subject of smooth flow of liquid in a pipe, and I'd like to take you in a direction few humans are able or willing to think. I'd like to examine the interaction between water molecules and the wall of the pipe. The atoms in the wall are bound to each other with bonds created by the release of energy during the bonding process, which I understand to be a combination of pressure and temperature. As water molecules encounter the atoms in the matrix of the wall, they have momentum that (I gather) is able to dig atoms of metal right out of the wall. I'd like to find the material that is most resistant to attack by water molecules, because I want to push a lot of water molecules through a pipe, and I want the pipe to last for a very long time. I am guessing that the best material for the surface of the wall will have very strong covalent bonds, and that the atoms will be closely packed. Do you have any data from your training through January of 2022 that considers this problem at the molecular level?

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Your description captures the essence of fluid-structure interaction at the atomic and molecular levels, especially the potential wear or erosion mechanisms that can occur. The molecular interaction between water and the walls of a conduit is a topic of considerable research in various scientific fields, from fluid dynamics to material science.

To address your query, we'll consider a few key points:

Corrosion and Erosion: In terms of the wear and tear a pipe might experience, there are two main mechanisms you seem to be addressing: corrosion and erosion. Corrosion relates to the chemical interaction between a material (often metal) and its environment (like water), leading to a change in the material's properties. Erosion, on the other hand, concerns the physical wear and tear due to the movement of the fluid.

Covalent Bonds & Close Packing: You're correct in assuming that strong covalent bonds in materials can offer resistance against physical and chemical attacks. Additionally, closely packed atomic structures (like in metals) can provide mechanical strength. However, a strong covalent bond or closely packed structure alone isn't sufficient to ensure resistance against water erosion or corrosion.

Material Choices:

- **Stainless Steel:** This is often used for its corrosion resistance. The chromium in stainless steel forms a passive layer of chromium oxide that prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure.
- **Plastics and Polymers:** Polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP) are often used for water transport because of their resistance to both erosion and corrosion.
- **Ceramics:** They have strong covalent and ionic bonds, making them resistant to wear. However, their brittleness can be a drawback.
- **Titanium:** Known for its impressive strength-to-weight ratio and its resistance to corrosion, especially in seawater.
- **Tungsten Carbide:** Used in situations with high erosion because of its extreme hardness.

Velocity and Erosion: The velocity of water plays a significant role in erosion. If you're moving water at very high velocities, erosion can become a significant concern, especially in bends or joints where the water's momentum can cause scouring.

Molecular Interaction: At the molecular level, water's ability to "dig atoms out" from the material isn't solely a matter of kinetic interaction. Chemical potentials, electrostatic interactions, and the solubility of the material in water can all play roles. For instance, water can corrode iron not just by physical interaction, but due to electrochemical processes leading to rust.

Passivation: Some materials can form a protective oxide layer when exposed to an oxidizing environment. This layer can protect the underlying material from further erosion or corrosion.

For long-lasting pipes under high flow conditions, you might want to consider materials that are both erosion-resistant and corrosion-resistant, especially if the water contains any dissolved chemicals, minerals, or other solutes. The choice would also depend on other factors like temperature, pressure, the specific impurities in the water, and the pipe's geometry.

Lastly, advancements in material science and engineering could provide newer solutions beyond 2022. For the most recent and application-specific information, consulting material scientists or engineers in the field of fluid dynamics and pipe design would be beneficial.



Thank you for accepting the opening premise of this dialog, and for your identification of candidate materials. The application is a kind of centrifugal pump. The base material to be

delivered through the device is water. The kind of water to be delivered is variable, and the amount of filtering needed is intended to be minimal. For example, sea water could be an input, and filtering would exclude objects that are greater than a millimeter in size. Even more ambitious is the prospect of harvesting comet water, which will be loaded with dissolved materials even more densely than sea water. You will have deduced that the application is space propulsion. You and I have made considerable progress conceptualizing a mechanical propulsion system, and now I am back to focus upon the nature of the material against which the water molecules will be interacting under great pressure. You mentioned Tungsten as a leading candidate for the lining of the pipe that will carry the water from intake to an exit port. Can a layer of Tungsten be laid over a steel pipe wall, to protect the steel from damage by the moving liquid?

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Your space propulsion application is intriguing, especially the idea of harvesting comet water as a potential source of propellant. The unique challenges posed by such an endeavor demand careful material choices.

To address your specific query about tungsten:

1. Tungsten Coating on Steel:

- Tungsten can be deposited onto steel, and this is often done using methods like Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD). These are common techniques used to apply thin film coatings of one material onto another.
- Another method is plasma spraying, where tungsten is heated to a molten state and sprayed onto the surface of the steel, where it solidifies to form a protective layer.
- Electroplating can also be used, though it might be more common for metals like chromium than tungsten.

2. Benefits and Challenges:

- Benefits: Tungsten has an incredibly high melting point (around 3422°C or 6192°F) and good wear resistance. It can serve as a protective barrier against erosion, especially if the water is moving at high velocities.
- Challenges:
 - Bonding: One challenge with coatings is ensuring a good bond between the coating (tungsten) and the substrate (steel). If the bond is weak, the coating might spall off under the influence of high-pressure flows.
 - Thermal Expansion Mismatch: Different materials have different thermal expansion coefficients. This can lead to stresses at the interface, especially if

there are rapid temperature fluctuations. This is particularly relevant in space applications, where temperature extremes are common.

- Corrosion: While tungsten is resistant to many forms of corrosion, it can form tungstic acid when exposed to alkaline solutions. If your water source (like comet water) contains alkaline impurities, this could be a concern.

3. Space-Specific Considerations:

- Temperature Extremes: Space environments can expose materials to extreme temperatures, especially without an atmosphere to moderate them. Tungsten's high melting point makes it suitable for high-temperature applications, but the temperature difference between sunlight and shadow in space can cause material fatigue due to repeated expansion and contraction.
- Radiation: Space radiation can cause material degradation over time. While tungsten has good radiation resistance, it's still a factor to consider, especially for prolonged missions.
- Vacuum: Some material properties can change in the vacuum of space. Ensure that tungsten's properties in a vacuum align with your requirements.

Considering the ambitious and innovative nature of your project, you'd likely benefit from a multi-disciplinary team that includes materials scientists, aerospace engineers, and fluid dynamics experts. They can guide material choices and design considerations, ensuring optimal performance in the challenging space environment.



Thank you for confirming that there are ways to incorporate a layer of Tungsten into the surface of a steel pipe. The question of heating is an interesting one, and I'd like this next exchange to focus upon it. The water intended to be delivered to the intake of the pump will have been heated to just below boiling. The system in which the water is contained would not be exposed to vacuum. Heating would be done using waste heat from a fission reactor which is tasked with providing electricity to drive the centrifugal pump. The water would enter the intake of the centrifuge at a temperature of less than 100 degrees Celsius. What I'd like for you to think about now, is to what extent the water molecules in the flow will be heated by their interaction with the wall of the pipe on their way to the exit port. What would be the reason for such heating?

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When water flows through a pipe, especially at high velocities or under high pressures, there can be various mechanisms leading to an increase in the temperature of the water. Here's an exploration of those mechanisms:

1. Frictional Heating:

- As water flows through a pipe, there's a frictional force between the water and the wall of the pipe. This frictional force can cause heating.
- In turbulent flows (which are common at high flow rates), there's internal friction within the fluid itself, between different layers of fluid moving at different velocities. This internal friction can also produce heat.
- Frictional heating can be significant, especially in high-pressure systems where the flow velocities are substantial.

2. Viscous Dissipation:

- As water moves, there's a viscous force that resists its motion. The work done against this viscous force is dissipated as heat within the fluid.
- This is essentially a subset of frictional heating but focuses on the internal resistance to motion within the fluid due to its viscosity.

3. Compressibility Effects:

- While water is largely incompressible, under extreme pressures, it can exhibit slight compressibility. When water undergoes compression and then expansion (such as in turbulent eddies or in high-pressure pumps), there can be heating due to these compressibility effects.

4. Cavitation and Re-entrant Jet Heating:

- In pumps, especially high-speed ones, cavitation can be a concern. Cavitation occurs when the local pressure of the fluid drops below its vapor pressure, causing the formation of vapor bubbles.
- These bubbles can then collapse when they move to regions of higher pressure. The collapse of these bubbles is violent and can cause localized heating, both from the adiabatic compression of the vapor inside and from the "re-entrant jet" that forms during bubble collapse.
- While cavitation primarily leads to material damage (erosion), the associated heating can't be entirely ignored.

5. Conductive Heating from the Pipe:

- If the pipe wall itself becomes hot (from external sources or from frictional heating), it can transfer heat to the water via conduction.

- Given that your water is being heated to just below boiling and your system may incorporate waste heat from a fission reactor, this conductive mechanism might play a significant role.

6. External Radiation:

- Although in your case the system isn't exposed to vacuum (and presumably not to outer space directly), in other scenarios, radiation (both solar and from other sources) can heat the pipe, which in turn can heat the fluid.

The exact temperature increase would depend on various factors, including the flow rate, pressure, pipe material and roughness, initial water temperature, and the length and diameter of the pipe. Computational Fluid Dynamics (CFD) simulations are commonly used to model such scenarios and predict temperature profiles in fluid systems.

In summary, water in a high-pressure, high-velocity system can experience heating due to a combination of frictional, viscous, compressibility, and conductive effects. The extent of this heating would need to be quantified based on detailed system parameters.



Thank you for your considering of the question of heating of water flowing in a pipe. I had not considered the interactions of the water molecules themselves as they are rather violently compressed against each other due to the very high G forces that would be needed. I appreciate the awareness that heating of the water is an unwanted drain on the energy invested in acceleration. You are (of course) aware that water molecules are heated to very high temperatures in the combustion chamber of a hydrogen/oxygen rocket. I now understand that the thermal energy invested in those molecules is a loss that must be accepted as the price to pay for propulsion. Some fraction of the chemical energy invested in creating hot water in a rocket engine is NOT available for propulsion, but is instead expended in heating the exterior environment. I've never seen figures on that loss? Do you have access to records of such a study?

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You're right in noting that not all the energy released during the combustion of hydrogen and oxygen in a rocket engine is converted into kinetic energy of the exhaust and, thus, not all contributes to propulsion. Some of the energy indeed goes into heating the combustion chamber, the nozzle, and is radiated away. However, rocket engines, especially those using

hydrogen and oxygen, are still among the most efficient propulsion methods in terms of their specific impulse.

In terms of the energy losses in a rocket engine:

Combustion Efficiency: This refers to how completely the propellants burn. For hydrogen/oxygen engines, this is typically very high, often above 99%. However, even if combustion is complete, it doesn't mean the energy release is entirely efficient for propulsion.

Thermal Efficiency: This relates to how well the heat from combustion is converted into kinetic energy of the exhaust. There are inherent limits to this, governed by thermodynamics. Rocket engines, as they are open systems, don't have a "thermal efficiency" in the same way closed systems (like car engines) do, but a similar measure can be derived.

Nozzle Efficiency: Not all kinetic energy in the combustion chamber is converted into directed (axial) kinetic energy in the exhaust. The design of the nozzle, its expansion ratio, and the ambient pressure all affect this. Over-expanded or under-expanded nozzles can lead to efficiency losses.

Radiative and Conductive Losses: A lot of the heat from the combustion process can be radiated away or conducted into the engine materials, especially at high combustion temperatures. Hydrogen/oxygen combustion can reach temperatures around 3000°C (5400°F), so these losses can be significant.

Boundary Layer Losses: A layer of cooler gas adheres to the walls of the combustion chamber and nozzle, protecting the walls from the hotter combustion gases. While this is necessary for engine longevity, it can reduce efficiency since the cooler gases have a lower velocity when they exit the nozzle.

Other losses: These can include losses due to incomplete combustion, shock waves, and flow separation in the nozzle, among others.

Regarding your query on specific studies: While the exact efficiency and breakdown of losses for specific engines might be proprietary or specific to each design, there are many studies, textbooks, and research papers on rocket propulsion that discuss these factors in detail. One of the definitive texts on this subject is "Rocket Propulsion Elements" by George P. Sutton and Oscar Biblarz, which delves into the complexities of rocket engine design and efficiency considerations.

To get a precise breakdown for a specific engine or design, you would likely need detailed performance data or simulations tailored to that engine. However, despite these losses, the high exhaust velocities achievable with hydrogen/oxygen combustion make it a highly effective propulsion method, especially for certain space missions.



The issue we are attempting to address is the inadequacy of the hydrogen/oxygen solution for delivery of a 5000 metric ton space craft from Earth to Mars. The team lead has performed analysis of all available known solutions, including nuclear thermal propulsion, and none are suitable for the stated problem. To be sure, All solutions would work. The reason for the present inquiry is to see if there is a solution available that has not been considered by others. This search led to the possibility that a carefully designed centrifugal pump might be designed to achieve a performance at the level needed. It was agreed that a 3D Printer might be able to place atoms in the configuration needed for this pump, since no known casting process could achieve the complex interior that (we think) would be needed. However, if Tungsten is to be laid at the surface of the interior walls of the pipes for liquid to be accelerated, then advances in 3D printing technology will be needed. Let me invite your consideration of a question about angle of attack. The design team has two variables to work with... we can change the radius of the pump, and we can change the length of the cylinder within which the water is to be accelerated. We call the concept a "Stretch Centrifugal Pump". This leads to the question for you: Is there an angle of attack that allows Tungsten to avoid damage by water molecules or is the degree of damage related to the angle of attack of the atoms to be accelerated?

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The approach you're describing, seeking innovative solutions to the challenges of long-distance space travel, is an admirable pursuit. The idea of a "Stretch Centrifugal Pump" and its implementation is intriguing. Let's delve into the angle of attack question and its relevance to material damage.

When discussing the "angle of attack" in the context of water molecules impinging on a tungsten surface, we're essentially talking about the angle at which the water molecules strike the surface. This can indeed influence erosion rates and mechanisms, especially in high-velocity scenarios:

Erosion at Direct Impingement:

- If water molecules (or droplets, in the case of any non-gaseous phase present) strike the surface head-on, or near 90°, the impact can be more erosive. This is

because the kinetic energy of the water molecule is largely imparted directly to the surface.

Erosion at Shallow Angles:

- At very shallow angles, the molecules might glide or skim along the surface. While the immediate impact might be less erosive, there can be shear effects, potentially leading to erosion, especially if there are any particulates or impurities in the water.

Cavitation:

- Independent of the angle of attack, cavitation, which we discussed earlier, remains a significant concern. The implosion of cavitation bubbles can cause damage regardless of the angle at which the bubbles form or collapse relative to the surface.

Velocity and Pressure:

- The velocity and pressure of the water are critical. Even at optimal angles to minimize direct impact erosion, very high velocities or pressures can still cause significant damage.

Surface Roughness and Microstructure:

- The microstructure of the tungsten surface can influence erosion. For instance, if the tungsten layer has grain boundaries, defects, or porosities that are aligned or oriented in a particular direction, they might be more susceptible to erosion at specific angles of water molecule impact.

In conventional erosion studies (like with sand or other abrasive particles), there's often an "optimal" angle at which erosion is maximized, and this angle can vary based on the material and the eroding particle. However, for water molecules on tungsten in the context of a high-speed centrifugal pump, the scenario is quite unique, and traditional erosion studies might not directly apply.

Given the uniqueness of this application, experimental studies or detailed simulations would be essential to understand the exact erosion behavior at different angles. Computational Fluid Dynamics (CFD) coupled with erosion models can provide insights, but validating those insights with experiments would be crucial.

Lastly, regarding the use of 3D printing for tungsten: While 3D printing technologies are advancing rapidly, printing tungsten, especially with the precision you might require, remains challenging. The high melting point of tungsten complicates traditional melting-based 3D

printing techniques. However, methods like binder jetting followed by sintering or powder-based methods could be potential avenues to explore.

Given the complexities involved, a multi-faceted approach, involving both simulations and experiments, would be necessary to optimize the design and minimize erosion in such a system.



We've covered a lot of ground. Thanks for another interesting and helpful session. Best wishes for similar success with all your other fans, world wide!

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Thank you for the engaging discussion! It's always a pleasure to delve into challenging and innovative topics. Best wishes for your project and endeavors. Don't hesitate to return if you have more questions in the future. Safe travels on your journey to Mars, even if it's just in the realm of thought experiments for now! 😊🚀🪐

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