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Chemical Engineering for Entrepreneurs

Agitators and Agitated Tanks

Agitators and agitated tanks are one of the basic functional unit operations of chemical processes. They make up the building blocks of all storage, reactor and separation systems. Here are the common considerations in their application.

The standard model is a square batch where the height of the liquid matches the diameter of the tank, of T=Z. Usually included are a center top entry agitator, baffles, and a bottom geometry that depends upon the function of the tank. If you are trying to suspend a solid or emulsify immiscible liquids, a dish bottom tank is used to ensure proper mixing of the phases. If the resulting emulsion is transparent this is usually a visual indication that it is stable, if it is translucent it is not stable. If you are trying to separate the liquid phases, settle solids, or precipitate solids that form as a result of a liquid phase reaction, a cone bottom tank is used. Flat bottoms tanks are for clear liquid storage.

Usually square batch tanks are 12 foot diameter by 12 foot liquid fill height in the tank. Many plants use the term “innage” to describe the liquid volume in the tank. This is the correlation between the height of the liquid from the bottom of the tank and its associated volume. The opposite approach many other plants use is the “outage” this is equivalent to the freeboard which is the difference in height from the overflow of the tank to the top of the liquid in the tank. In some applications freeboard is critical for disengagement of foams, gases, and other tank separation products.

A 12 ft by 12 ft tank is easily scaled down using a 12 inch by 12 inch laboratory scale equivalent. The other critical parameters in scale down include holding the geometric ratios between impeller diameter, impeller height off the bottom, and baffle width constant. Other scaling factors include agitator shaft rotational speed, number of baffles, pitch of the impellor blade, and number of impellors. These geometric ratios for the tank, coupled with fluid characterization ensures success in scale up.

From a practical matter the largest shop fabricated tanks are usually 30,000 to 35,000 gallons. This is equivalent to a 14 foot diameter by 33 foot long tank. This is because of the limitation to shop fabricate and ship to site. Shipping is usually limited by the 15 foot minimum interstate highway bridge clearance. The 12 foot by 12 foot basis has evolved over time to include nozzle extensions, lugs, lifting eyes, jackets, and external pipe supports to maintain the 14 foot transportation envelope.

Tanks can be classified for different purposes. For instance, reactors and precipitators should be square batch. Simple mix tanks or blending tanks can be taller than the square batch. These are the cases where you might use multiple impellors. Multiple impellors are modeled using an upper square batch and a lower square batch model with usually a 20% overlap. This helps set the dimensions for both the upper and lower mixing zones.

For slurries a special type of second impellor is a tickler. A tickler is a smaller diameter impellor that sits about one pipe diameter above the bottom outlet discharge nozzle. This impellor is usually 20-25% of the diameter of the main impellor. It is to keep the slurry moving through the discharge without creating a plugged cake.

Usually in atmospheric tanks you have a half a diameter freeboard above the liquid level to the top of the tank.

There are many precipitation tank and agitator geometry models. The models are only as good as the lab scale and pilot scale data collected using geometrically similar arrangements. Computational fluid dynamics, CFD, is a good visual modeling method, but it too is dependent upon actual lab and pilot scale performance characterization using actual experimental run data.

People define mixing in different ways. To say the mixing is good is not a very clear or well defined statement. Even the qualitative “Chem Scale” from Chemineer of 1-10 is difficult to quantify in scale-up. A more rigorous method to define complete mixing agitation would be to measure concentration of different reactor species over time, loss of reagent over time, slurry density over time, or the point when the concentration rate of change goes to zero.

Mix tanks should always have baffles. Normal aspect tanks for mixing, 1:1 height-to-diameter, should be specified. Avoid high aspect mix tanks and avoid high agitator speeds to avoid radial stresses on the gear box.

Typical material characterization properties that are needed are:

1. Physical properties of the materials involved
    a. Specific gravity and density for both of clear liquid systems, slurry systems, and solid particles that make up the slurry
    b. Particle size distribution
    c. Weight percent of solids in the slurry
    d. Rheology curves, not just one viscosity measurement
    e. Liquid droplet size distribution for oil/water systems
    f. Surface tension of the liquids
    g. Temperature effects on all physical properties
2. Process operating conditions
    a. Pressure
    b. Temperature
    c. Concentration of constituent reagents and products

3. Geometric parameters
    a. Tank diameter to liquid height
    b. Height of agitator above bottom
    c. Impeller diameter to tank diameter
4. Agitation conditions
    a. Tip speed
    b. Pumping capacity
    c. Scale up model
5. N_{js} just suspended speed correlations
6. Correlations for solid liquid mass transfer
7. Materials of construction evaluation and selection criteria

Materials of Construction

Tank agitators are subject to both corrosion from the chemical constituents that make up the reagents and products, and in the cases of slurries, from erosion from the particles moving at a high rate of speed in the tank. Many times a metal that is superior in corrosion resistance properties is not as well suited for erosion resistance. Corrosion erosion cycles are some of the toughest services for agitators. Temperature plays a significant role in the selection of materials as corrosion is accelerated at higher temperatures. Material selection of the ancillary components of the assembly must consider the environmental exposure aspects of those materials even if not in direct contact as wetted parts. The disassembly, removal and reassembly of the equipment components shall not be dependent upon destructive removal methods.

Any lined tanks or components must be installed and provided with the proper confined space entry, CSE, access enabling in-tank repairs to occur with the tank or equipment in place. In the process systems general arrangements considerations must be given to the fact the agitator will have to be removed from the vessel at some time in its service life. Removal and re-installation disassembly and re-assembly pathways must be shown. Provisions must be made in the overall equipment arrangement for the complete removal of specific vessels that have a high probability of severe lining or other catastrophic failure that will require its complete removal and replacement as a whole unit. Agitators should be designed with replaceable blades. Baffles placed in tanks with erosive solids should be designed to be replaced. In addition gradual curved edges and sloping gradual surfaces shall be designed into erosive service versus the usual sharp edge components. Added attention to bolt material specifications, locking and torque, is critical in both erosive and corrosive applications. Consider blade attachment, hub attachment, and coupling attachment. Special strength and corrosion resistant bolts should be on critical spare parts list.

Thermowells in slurry tanks shall not be placed in nozzles in the bottom of the tank as the protruding thermowell will wear and create a leak point in the vessel. Thermowells shall be placed in through nozzles in the top of the tank and shall be protected by being placed on the downstream side of a baffle.

Rubber lined carbon steel tanks should have the minimum number of nozzles in the sidewall and bottoms of the tank. One larger diameter nozzle with a header take off for multiple bottom discharge needs is better than multiple discharge nozzles in the bottom and side of the tank. External stilling wells and pump tanks can solve the problem of needing multiple nozzles in the main vessel wall.

If using rubber lining with the hard particle containing slurries the rubber lining shall have a hardness and toughness such that the particles can imbed in the lining and create a self repairing wear surface.

Testing at condition for failure or continued long term testing of possible successful candidates is the only way to insure the correct materials are chosen for the service.

For lined tanks or dual laminate tanks, material wear indices are difficult to correlate. Two materials that have the best Taber abrasion resistance values (ASTM D1044) for thermoplastics that can be fabricated economically into a suitable composite laminate tank. The Taber for Kynar and Halar is about 15. Teflon's Taber is in the 1000 range. A lower number means higher abrasion resistance. Taber is an abrasion resistance index. When comparing rubber which uses Shore A (chlorobutyl rubber linings) versus the proposed thermoplastics (ETFCE and PVDF) the correlations are very well developed and difficult to draw conclusions.

Abrasion resistance indices are more of an art, and the Taber (and other common hardness indices like Shore and Rockwell) probably do not give good indication of the durability prediction for the material in this service. Torture testing is required.

The crystallinity of the thermoplastic is a significant factor coupled with its friction coefficient and abrasion resistance index. Combining these with a toughness factor is hard to characterize and predict.

Silica carbide in the resin in the corrosion liner is another method of creating a material with superior wear properties. The surface resin wears quickly during first use leaving a peak and valley surface with silica carbide particle exposed to the hard moving particles. The moving particle hits the silica carbide particle in the wall and has no effect. The failure mechanism here to determine is whether the resin can keep the particles of silica carbide stable in the surface layer or will they be ripped out of the resin matrix and lost to the fluid.

The selection of any metallic alloy for the agitated tank and agitator service must be clearly supported by detailed definition of the alloy, the data upon which the selection is made, and the details of the heat treating, welding methods and other forming methods that will be used on the part as all these details affect the suitability for the services.

There are great differences between each of the Hastelloy family of alloys. Many vendors only use the generalized corrosion charts whereas the plant has had service life experience. Hastelloy B2 and B3 are Ni-Mo alloys. They are shown in the books as having excellent resistance to HCl as long as no oxidizing species are present. Hastelloy C, C4, C22, C276, and

C2000 are all Ni-Cr-Mo alloys. These are generally better in HCl with oxidizing impurities, but are affected by higher temperatures to a greater extent. There is also the consideration of the differences between cast and wrought material. The wrought parts may be fine (as in the case of tank wall plate or impeller plate, but the equivalent cast parts (bolts and nuts) may not be the same mean time between failures. Incorrectly using wrought data in a cast part application determination may lead to the incorrect material specification choice. The same considerations must be taken into account specifying the Nickel 200 for the hot caustic service versus the then step down in alloy selection with the reduced temperature Alloy 20 that can be used in the lower temperature caustic service.

