1. Is Pulse Width Modulation (PWM) drive used to reduce torque pulsation (cogging) at low speeds?
2. Is a totally enclosed fan cooled (TEFC) motor used with a constant speed fan or booster fan as necessary with class F insulation (inverter duty) and 1.15 service factor to prevent overheating? Is a totally enclosed water cooled (TEWC) motor needed for high temperatures to prevent overheating?
3. Is a NEMA frame B motor used to prevent a steep torque curve?
4. Is the pump sized to prevent operation on the flat part of the pump curve?
5. Is a recycle valve needed to keep the pump discharge pressure well above static head at low flow and a low speed limit needed to prevent reverse flow for highest possible destination pressure? See article "Watch Out for Variable Speed Pumping" (reference 19 in Appendix A).
6. Are signal input cards of greater than 12 bit used to improve the resolution limit of the signal to 0.05% or better?
7. Do the drive and motor have a generous amount of torque for the application so that speed rate-of-change limits in the drive setup do not prevent changes in speed that are fast enough to compensate for the fastest possible disturbance?
8. Is excessive deadband introduced into the drive setup, causing delay and limit cycling?
9. For tachometer control, does the magnetic or optical pickup provide enough pulses per revolution to meet the speed resolution requirement?
10. For tachometer control, is the speed control kept in the VFD to prevent violation of the cascade rule where the secondary speed loop should be 5 times faster than the primary flow loop?
11. To increase rangeability to 80:1, is fast cascade control of speed to torque in the VFD considered to provide closed loop slip control as described in *The Control Techniques Drives and Controls Handbook*, IEEE Power and Energy Series 35, Cambridge University Press, 2001?

10. Checklist for Virtual Plant

The following is a checklist to help trigger the right thought processes for arriving at a simulation that will meet your objectives for Systems Acceptance Testing (SAT), Operator Training Systems (OTS), and Process Control Improvement (PCI). Questions 18 through 30 are for first principle models. In general, you should start with a tieback model, increase tieback model fidelity by step response models, and develop a first principle model with valve, measurement, and process dynamics adjusted to match the step response models. Note that dead band, resolution, and threshold sensitivity will affect the open loop gain but not the deadtime in step response models.

1. Are the actual displays and trend charts used in the control room loaded and the actual configuration downloaded into the virtual plant?
2. For an SAT, does the simulation write and read to the actual I/O assignments?
3. Do you have the Process Flow Diagrams (PFD) and Piping & Instrument Diagrams (P&ID)?
4. Do you have the operating procedures and control definitions?

5. What are the simulation fidelities needed for SAT, OTS, and PCI?
6. Which are the most important loops for achieving the required fidelity?
7. Have you setup scenarios to automatically test the ability to deal with abnormal situations?
8. Can you play back the scenarios?
9. Do you have an automatic grading system of time and accuracy of solution for the scenarios?
10. Can you speed up the dynamics so scenarios are completed in less than an hour?
11. Have you retuned the controller for the new time constant to deadtime from speedup?
12. Have you provided a way of resetting compositions, levels, pressures, and temperatures?
13. For the important loops, do you have the open loop gain, deadtime, and open loop time constant identified from an adaptive tuner or rapid modeler for a step response model?
14. For the important loops, do you have two operating points to provide the biases for the controller output ($\%CV_0$) and process variable ($\%PV_0$) to enable the use of an open loop gain (K_0) based on deviation variables in a step response model as seen in equation below?
15. For the important loops, have you modeled the control or variable frequency drive deadband, delay, lag, deadtime, installed characteristic, rate limiting, resolution, and threshold sensitivity?
16. For the important loops, have you modeled the measurement delay, lag, noise, resolution, and threshold sensitivity, including wireless default update rate and analyzer cycle time?
17. For DCS simulate mode have you interfaced model outputs to AI block simulate inputs and AO block outputs to model inputs? (Interfacing PID will bypass AI filter and AO valve action.)
18. Do you have the chemical name, formula, and physical properties (e.g., molecular weight, density, vapor pressure, phase enthalpies, and boiling point for liquids) for each component?
19. Do you have the stoichiometric equations, yield, and kinetic equations for reactions?
20. Do you have the seed, growth, and attrition kinetic equations for crystals and cells?
21. Do you have equipment volumes and pump and compressor curves?
22. Do you have the cross-sectional areas for levels?
23. Can you use an existing library of advanced modeling objects for unit operations, piping, final control elements (e.g., control valves and variable speed drives) and measurements?
24. Do you need to write modeling objects for missing unit operations in CALC blocks using:
    a) differential equations for material, energy, and component balances for all phases as exemplified in Appendix D?
    b) charge balance equation of acids and bases for pH with dissolved carbon dioxide added as a moderator of slope between 4 and 8 pH?
    c) mixing and injection delays?

d) driving force equations for heat and mass transfer with heat and mass transfer coefficients and areas and equilibrium relationships between vapors and liquids and between gases and dissolved gases?
e) equation of state for gas pressure (e.g., ideal gas law with compressibility factor)?
f) equations for final control element and measurement dynamics?
g) equations for kinetics and population balances?
h) equations for momentum balance for compressor surge control?
i) speedup factors for differential equations and kinetic equations?

25. Have you added flow control loops as necessary to reduce the dependence on a pressure-flow solver for flows in the virtual plant to match the flows in the actual plant?
26. If the controls cannot be speeded up in unison with the process model, have you scaled flows in proportion to kinetic rate and mass transfer rate speedup, kept the deadtime about the same, and decreased the controller gain by the differential equation speedup factor?
27. Have you commissioned and tuned level and pressure loops to keep inventories in bounds?
28. Have you commissioned and tuned remaining loops with setpoints to match the PFD?
29. Have you adjusted model parameters to match manipulated flows on the PFD or use model predictive control (MPC) to automatically adapt parameters to make manipulated flows in a virtual plant running in sync with same setpoints as real plant, as described in the *Control* magazine Nov. 2007 article "Virtual Control of Real pH" (reference 37 in Appendix A)?
30. Have you adjusted model parameters to match process gains (e.g., slope of pH titration curve) as described in the *Chemical Processing* magazine article "Virtual Plant Provides Real Insights" (reference 35 in Appendix A)?

Equation (3) in Tip #89 step response model in terms of deviation variables solved for *%PV*:

$$\%PV = K_o * (\%CO - \%CO_o) + \%PV_o$$