

Pump Performance Bands

DETERMINING TIGHT VS. LOOSE AND WIDE VERSUS NARROW FLOW WILL HELP OPTIMIZE A PUMP'S PERFORMANCE

By Wallace Wittkoff

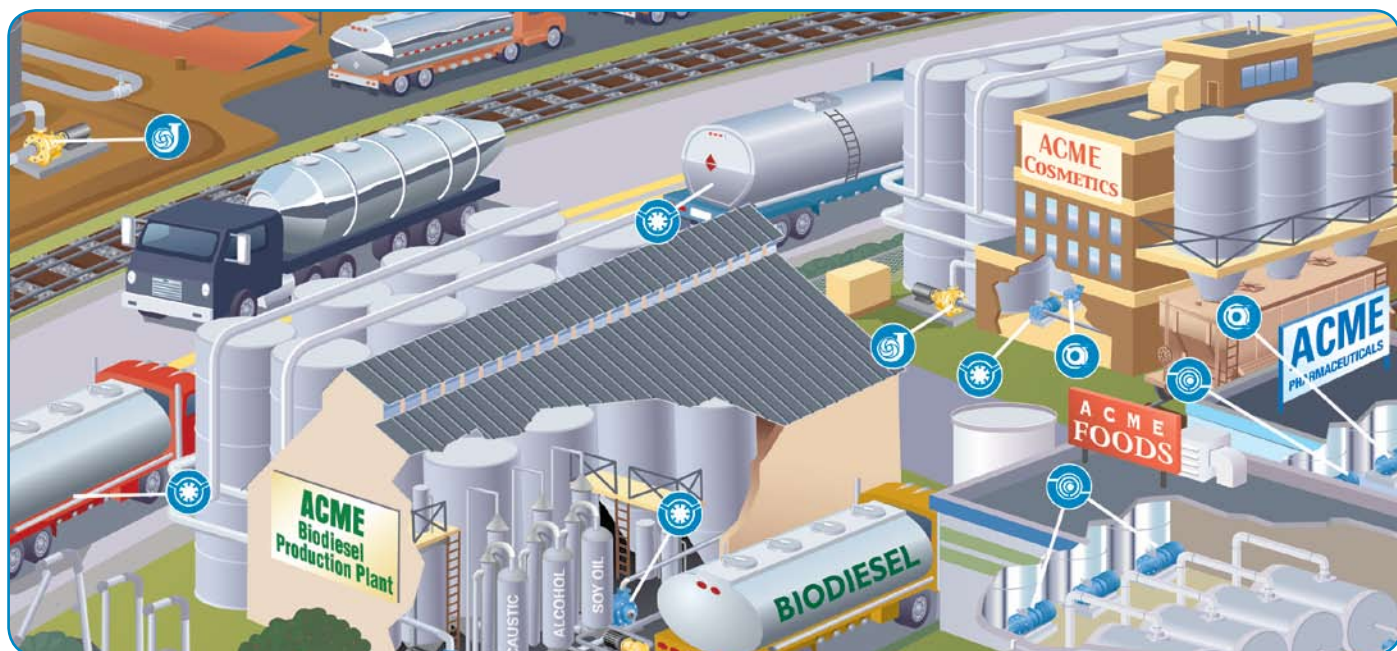


Figure 2: How pump affects micro and macro process efficiencies.

Introduction

Technical professionals understand a variety of fluid-transfer performance concepts. The principles have much to do with evaluating if an individual pump, on an individual/micro scale, will succeed in accomplishing its fluid-transfer duties with a reasonable degree of dependability. This includes evaluation of inlet/discharge conditions, flow, speed and power requirements, as well as durability.

This article explores a segment of the positive displacement (PD) pump arena where precise flow control is needed from a rotary-style PD pump (Figure 1). Despite the PD style of operation for these pumps, their use in precise metering applications has to be approached with caution because of the potential for excessive slip, which induces errors. Historically, instead of rotary pumps, reciprocating-type pumps have been favored in these types of applications. However, some processes cannot accept reciprocating-type pumps because of their inherent pulsation, cost, automation complexity, or other parameters. The NPSHr (net positive suction head requirements) and stuffing needs of reciprocating pumps are also a challenge.

	Reciprocating	Rotary
Transfer	Well Established Solutions	Well Established Solutions
Metering	Well Established Solutions	Pump Slip Can Limit Solutions, New Solution Available

Figure 1: PD Pump Principle/Service Matrix

The Challenge

Figure 1 outlines the learn concepts to evaluate the suitability of rotary positive displacement pumps for applications needing precise flow control with variable process conditions, while factoring in pump wear.

The application of advanced fluid-transfer concepts on a macro (or process) scale will enable entire processes to become efficient in addition to aiding the efficiencies of any specific pump. Users can find ways to produce a product at the least cost considering factors such as plant-wide labor,

floor space, capital investment, cleaning infrastructure and total process energy usage (Figure 2).

For instance, users could replace batch-blending processes with continuous in-line blending processes. New pumps with good metering/predictable flow performance are enabling this process method switch.

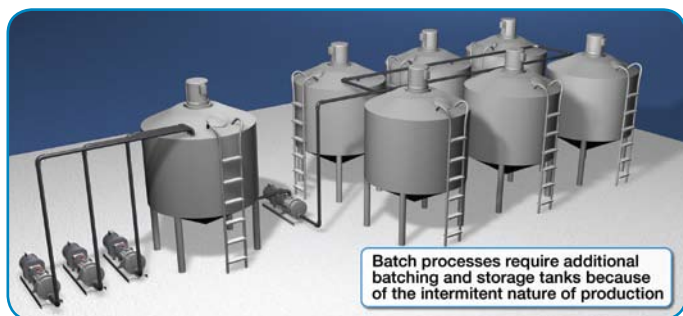


Figure 3: Batch process diagram

In its simplest form, a batch process (Figure 3) first involves sending ingredients in the correct amounts to a processing tank. Subsequently, and possibly in a distinct step, the products are mixed within the tank to produce the desired blended product. In contrast, with an in-line continuous-blend process (Figure 4), the ingredients are fed proportionally correct amounts and instantly combined as they are transferred within a common manifold. This manifold may also contain shearing devices to make sure the ingredients are properly mixed.

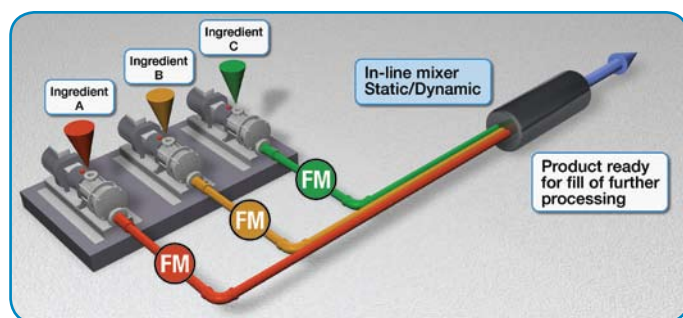


Figure 4: Continuous blend diagram

A full analysis of the benefits and drawbacks of truly continuous over batch processes are not possible in the scope of this article. In summary, however, continuous-batch processes can yield:

- Large reductions in floor space (no multi-stage blend tanks needed)
- Possible quicker product-formulation changes to match needs

- Reduced cleaning surfaces (eliminating multi-stage tanks)
- Capability of high degree of automation (recipe control)
- Reduced product losses and waste treatment

Several drawbacks in the use of continuous-blend processes have been caused by limitations in the pumping technology employed. Past and existing systems can be effective, but cannot accommodate wide changes in process parameters like flow rates (affecting proportion limits) and viscosity (ingredient flexibility). Additional issues with existing continuous in-line blending processes include stability as a result of startup/shutdown conditions, equipment aging and process upsets.

New pump technologies, as well as correct selection of existing technologies, are now enabling the wider use of continuous-blending processes that require more flexibility and stability.

Details on Pump Performance

A pump's "performance band" is the family of duty points (pump speed versus delivered flow rate) resulting from pump slip for a range of possible process conditions, including viscosity, back pressure, temperature and even pump wear during its lifetime. The pump performance band can be described as either tight or loose, which indicates how much the flow can change (think of slack) for a fixed pump speed. The performance band can also be described as wide or narrow to indicate the possible range of speeds the pump can run while producing flow.

From a practical standpoint for in-line blending applications, the tighter the pump-performance band, the better the metering accuracy under varying process conditions. At the same time, the wider the performance/flow rate band, the more flexibility in handling formulations that require a wide range of possible ingredient input flows.

This article explores these new concepts that take pump performance to the next level. In addition to the pump just simply working, the correct application of these pump concepts allows refinement of the transfer process, permitting new, enhanced applications that were previously not possible or reliable. The in-line blending process described above is one example. Other examples include coating, spray drying, filling, filtering and heat-exchange processes that require controlled flow with tight pump performance bands.

Tight Versus Loose Pump Performance

The root issue with rotary PD pumps is that the flow performance on all pumps is to some degree affected by internal clearances that result in slip. The degree of slip changes with:

- Viscosity changes
- Differential pressure changes
- Clearance allowances for temperature change
- Wear (resulting in an increase in clearance)

Given these product/process variables, tight performance occurs when the pump maintains close to its theoretical displacement independent of changes to the above variables. The definition of a PD pump is a pump that transfers a set displacement per unit operation, such as revolution or stroke.

Tight versus loose pump performance is the extent to which, under a given range of conditions, the pump maintains high volumetric efficiency. High volumetric efficiency is the extent (ratio) in which the true displacement of the pump approximates its theoretical displacement for given process/product conditions. Pump slip is the difference between the theoretical displacement and the actual displacement. Therefore, the lower the pump slip in any condition, the tighter the pump's performance under conditions of changing viscosity, pressure, temperature or wear.

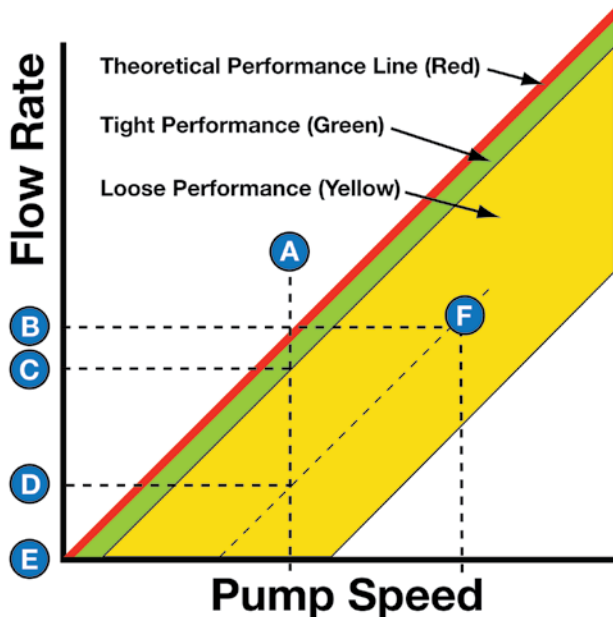


Figure 5: Comparative performance band

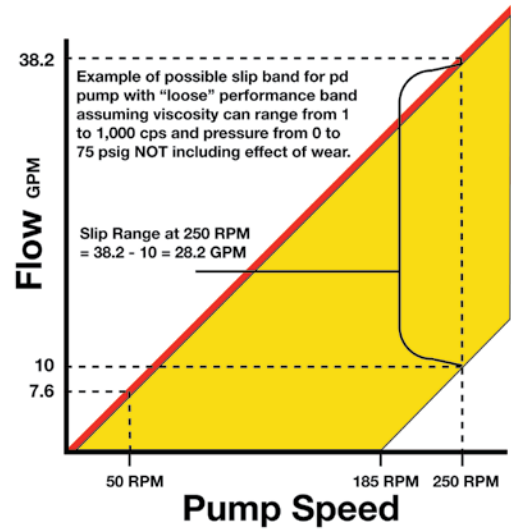


Figure 6: Example of pump curve with loose and narrow performance band

Classifying a pump as simply positive displacement without quantifying the tightness of its performance band can greatly affect the desired results in an application. The extreme example is one in which, regardless of the pump speed, the slip is 100%. That is, all fluid that is pumped forward then flows (slips) back through the pump's internal clearances to produce no net fluid transfer. While sounding dramatic, it is not uncommon that a pump reaches this point (total loss of flow) before it is taken out of service to be repaired or replaced.

To understand slip for traditional PD pumps, see Figure 5. It illustrates the possible loose-performance range (the yellow area) of a typical PD pump when operating in variable conditions (changes in viscosity, back pressure, temperature, and wear). This graph shows how flow for a given pump speed (A) can vary from the theoretical (intersection BA) to an extreme (intersection EA) which indicates no flow. This condition occurs in pumps with worn pumping elements, for example.

Even in non-extreme cases such as when needing a flow rate of (B), the pump would need to be accelerated from (A) to (F) in order to achieve the flow (B). This can prove to be an automation challenge and result in a reduction of reliability. If the automation system does not have a way to compensate for loss of flow and the pump remains at the same speed (A), the flow rate (D) would be inadequate. An actual curve for such a pump with 0.153 gallons/revolutions can be seen in Figure 6.

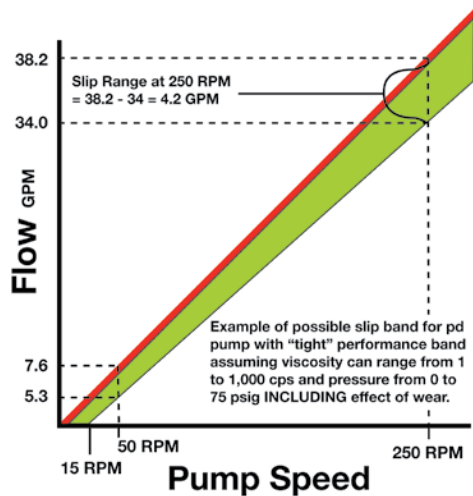


Figure 7: Pump curve with tight and wide performance band

Most users specifying pumps realize this and attempt to control the extreme variabilities of viscosity, pressure, temperature and wear simultaneously.

In many applications, this variation is sufficient to produce a challenging operational scenario. In some cases, advanced automation can help, such as using flow meters with speed/pressure control loops and back pressure stabilization valves. However, there are cases for which the possible variation cannot be compensated without recalibration or retuning the processes. These methods can prove costly or unfeasible, and could also increase system complexity (thus reducing reliability).

Figure 5 illustrates a tight performance band, which is shown as the green performance band range superimposed on the same graph. Even with large variations in pumping conditions within its published performance limits, the maximum variation in flow versus pump speed would be between (B) and (C) instead of (B) and (E), illustrated by the yellow loose-performance band. An actual curve band for such a pump can be seen in Figure 7. Both pumps (Figures 6 and 7) have a theoretical displacement of 0.15 gallons/revolution, but the curve in Figure 6 shows how loose the pump's performance is at 250 rpm, producing as much as 28 gallons/minute of slip while attempting to pump 38 gpm. The pump shown in Figure 7 has only 4 gpm of slip under the same conditions.

Today's advanced pump manufacturers provide the tools that permit evaluating the possible slip for a given application. Curves are supplied that demonstrate how to down-rate the flow given changes in back pressure, viscosity or change of internal component clearance to handle certain temperature

ranges. These tools are helpful for compensating for the performance. At times, however, these performance changes can't be adequately or reliably compensated and may not produce optimal control.

The Effects of Pump Component Wear

To further complicate matters, pump component wear invalidates most pump-performance curves. In highly variable conditions, wear cannot be accurately modeled or predicted. For processes that require tight and predictable performance over time, the solution is pumps that have tight performance ratios to begin with and are either immune to wear or can compensate for wear. Pumps can also be repaired to like-new condition. In doing this, there still remains the risk that the pump's performance will degrade before the anticipated rebuild point and cause production issues. Repair or replacement to regain proper pump performance can result in high costs for rotary PD pumps. In other words, the pump works mechanically just fine, but needs to be repaired to regain performance, which can be costly.

Loose pump performance also has associated side effects. These include an increased amount of shear that is imparted on the fluid, greater power requirements (and reduced efficiencies) of the pump and heat generation

Narrow Versus Wide Performance Band

This is not to be confused with tight and loose. In fact, in many cases a pump with a tight performance band gives it the ability to handle a wide flow performance range. The width of the pump's performance band describes the range

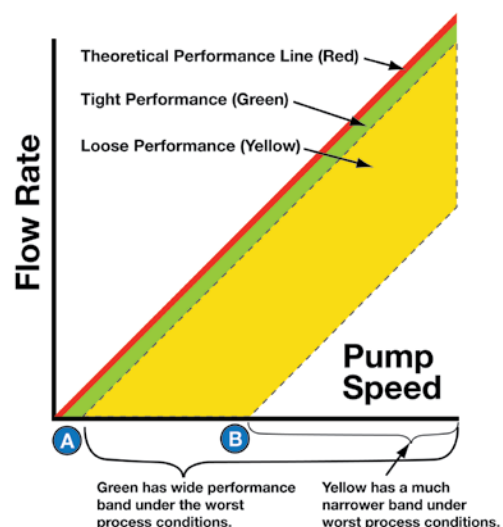


Figure 8: Comparison of wide and narrow performance bands

of speeds in which the pump can produce acceptable flow for the application. This is also sometimes referred to as the effective turn-down ratio of the pump, borrowed from terminology used in conjunction with motors or variable-speed drives.

In Figure 8, notice the point at which the green or yellow pump curves are at greatest slip point and cross the zero/no flow (x axis line). These are points (A) and (B) respectively. These are points in which the green and yellow bands, representing respective pumps, begin to produce flow under the greatest slip condition possible for the process. The pump that starts to produce flow at point (A) will use the total range of pump speed more effectively (revolutions per minute) than the pump starting at point (B).

The performance band width of a pump is also affected by the ability to drive the pump at low to high speeds. Torque requirement, gear reduction, motor cooling and variable-speed drive capabilities all play a part and are not in the scope of this article. Motor and variable-speed drive capabilities, for example, set lower and upper limits.

For an actual illustration of performance band width, refer back to Figure 6. Notice that a pump, in this case a typical lobe pump with a 0.153 gallon/revolution theoretical displacement, effectively has a narrow performance envelope. That is because under an arbitrary worst condition—in this case pumping 1 cP (water-like viscosity) fluid against 75 psig—the pump only begins to produce flow at 185 rpm. This means that speeds between 50 rpm to 185 rpm, which are considered good speeds for ensuring the long life of rotary PD pumps, are not available to the pumping process. The performance band is therefore narrow as it ranges from 185 rpm (instead of 0 rpm) to the maximum mechanical speed capability of the pump, or

some other process limitation like NPSHr versus NPSHa, or the abrasiveness of product.

In comparison, refer back to Figure 7, which shows the actual performance graph of a pump with a wide performance envelope. Notice that under the same conditions as Figure 6—pumping 1 cP product against 75 psig—flow begins to be produced at 15 rpm (instead of 185 rpm). In this case, on the low-RPM range, the pump in Figure 7 produces flow at a much wider range of RPMs than the pump in Figure 6.

The lobe pump curve shown in Figure 6 does not show how performance degrades as the pump wears. It is only a “snapshot” of the pump performance when it is new. This is the case with most PD pumps. If wear occurs in this pump, the manufacturer-supplied performance curve no longer applies and actual performance is unknown, unless verified in the field. In Figure 6, the point at which the pump begins to produce flow under wear conditions could be even greater than 185 rpm and prompt repairs.

In sharp contrast, the pump illustrated in Figure 7 compensates for wear by maintaining as-new clearances. Therefore, slip does not change, and the pump performance remains tight with a wide range of flow capabilities. Both the Blackmer® sliding vane pumps and Mouvéx® eccentric disc pumps share this phenomenon.

Our example application that exploits these needs—the continuous in-line blending process—benefits from pumps that have a high turn-down ratio. This is because the recipe to produce the final product can be highly variable as far as the content percentage of each ingredient. In other words, the wider the flow rate range that is achieved by the pump, the wider the variation of recipes that can be produced with the system.

Table 1: Pump type comparison.

Rotary Pump Type	Tight performance when new	Tight performance with wear	Dry Priming	Wet Priming Low Viscosity	Viscosity Handling above 15,000 cps	High Pressure Capability >250 psi	Uses Dynamic Seal	Hygienic Design	Large Particulate >1/2"
Progressive Cavity	Tight	No	No	Good	Yes	Yes	Required	Some	Yes
Gear Pump	Tight	No	Poor*	Medium*	Yes	Yes	Required	No	No
Lobe Pump	Loose	No	Poor*	Poor*	Yes	Yes	Required	Yes	Yes
Circumferential Piston	Medium	No	Medium*	Medium*	Yes	Yes	Required	Yes	Yes
Sine syle	Medium	No	Medium*	Medium*	Yes	No	Required	Yes	Yes
Vane Pump	Tight	Yes	Good	Good	No	Yes	Required	No	No
Eccentric Movement	Tight	Yes	Good	Good	No	No	No	Yes	No

* Typically will need to accelerate the pump to prime compared to product flow rate

Conclusion

Good flow control from rotary PD pumps offers options for more advanced processes, like in-line blending, that can have far-reaching influence on a production facility's overall capital and operating costs. Respected pump manufacturers offer performance curves that can be evaluated to determine if the performance band is comfortably suitable for the application. If not, alternative pumping technologies should be studied and considered.

Most curves do not show the effects of wear on performance. Therefore, if wear is anticipated during the expected life span of the pumps and their parts, more subjective analysis is needed. Some curves do model wear, so look for those. Even better, some pump technologies, such as Blackmer® sliding vane pumps and Mouvex® eccentric disc technology, compensate by eliminating clearances caused by wear. Therefore, determine if these pumps are applicable for the application.

Table 1 is a guide that compares different rotary PD pump technologies and how they compare regarding their performance bands and other criteria that may be important. Basically, the most important criteria for the process should be heavily weighted, but none of the criteria cause a disqualification.

In-line blending systems are already common in the beverage industry where the variation of ingredient viscosities can be controlled. Several suppliers specialize in these processes. Finding examples of more complex in-line blending processes that demand pumps with tight and wide performance bands is more elusive since they have been developed under proprietary restrictions and confidentiality. After all, these systems, when successful, give a clear advantage to the processor, one which they rightfully desire to keep and exploit.

References: This article builds on the principles presented in the Hydraulic Institute's "PD Pump Fundamentals, Design and Applications (Part One)" (Pumps & Systems, February 2009, available on www.pump-zone.com).



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