2.2.2 CENTRIFUGAL PUMP PACKING

JAMES P. NETZEL

Packing is used in the stuffing box of a centrifugal pump to control the leakage of the pumped liquid out, or the leakage of air in, where the shaft passes through the casing. This basic form of a seal can be applied in light- to medium-duty services and to those liquids that prove difficult for mechanical seals.

THE DESIGN OF PACKING RINGS

Packing may be referred to as compression, automatic, or floating. Each term describes the type of operation in which the packing will be used.

Automatic and floating packings require no gland adjustments in controlling leakage. Automatic packings are confined to a given space and are activated by the operating pressure. Automatic packing rings are designed in the form of V rings, U cups, and O rings. Floating packing includes piston rings and segmental rings that may be energized by a spring. These types of packing are commonly used in reciprocating applications.

Compression packing is most commonly used on rotating equipment. The seal is formed by the packing being squeezed between the inboard end of the stuffing box and the gland (see Figure 1a). A static seal is formed at the ends of the packing ring and at the inside diameter of the stuffing box. The dynamic seal is formed between the packing and shaft or shaft sleeve. Under a load, the packing deforms down against the shaft, controlling leakage. Some leakage along the shaft is necessary to cool and lubricate the packing. The amount of leakage will depend on the materials of construction for the packing, the operating conditions of the application, and the condition of the equipment.

Packing must be able to withstand equipment variables (see Figure 1b). The design of the packing ring and the materials of construction must be resilient to follow shaft runout and misalignments, as well as to compensate for thermal growth of the equipment without an appreciable increase in leakage.

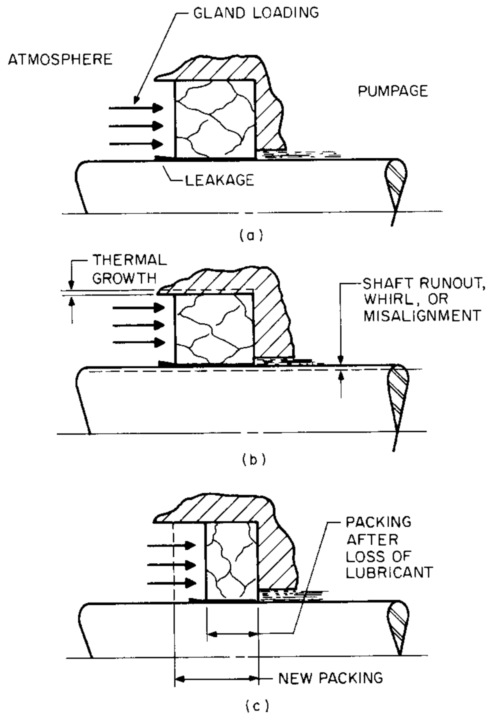

FIGURE 1 Compression packing; (a) new packing installation, (b) installation variables, (c) installation after many adjustments

As rotating equipment is operated, the load on the packing must be adjusted to control leakage (see Figure 1c). Care should be taken not to overtighten the packing. Most compression packings have a lubricant designed into them to prevent overheating of the packing or scoring of the shaft. Repeated adjustments will drive some of the lubricant from the packing, which will result in reduced operating time.

Compression packings are made of twisted, braided, woven, or wrapped elements formed into square or round cross-sections or other configurations. Square cross-sections are more common for rotating equipment.

A selection of the proper materials for the packing must include the chemical resistance to the product being sealed as well as the temperature, pressure, and shaft speed. Complete lists of the construction materials, packing lubricants and binders are given in Tables 1 and 2.

OPERATING FUNDAMENTALS

The Size and Number of Packing Rings The number of packing rings may vary, depending on the objective of the sealing system or the requirements of the rotating equipment. The most common packing arrangement for rotating equipment is illustrated in Figure 2. Three rings of packing are used to seal the process liquid from the packing lubricant. Two rings between the lantern and gland are used to restrict the leakage of the lubricant to the atmosphere. The size of the packing depends on the size of the equipment. Typically, for rotating shafts, the standard square size packings shown in Table 3 may be considered.

TABLE 1 Common materials of construction for packing

Fibers				Metals
Mineral	Animal	Vegetable	Synthetic	Lead
Metal	Wool	Flax	Nylon	Copper
Graphite	Hair	Ramie	Rayon	Brass
	Leather	Jute	TFE	P-bronze
		Cotton	Carbon	Aluminum
		Paper	Aramid	Iron
			Polyamide	Stainless Steel
				Nickel
				Monel
				Inconel
				Zinc

TABLE 2 Common lubricants and binders for packing

Lubricants		Dry Lubricants	Binders
Mineral	Animal	Graphite	Grease
Lube Oil	Tallow	Moly	Waxes
Paraffin	Glycerol	Mica	Elastomers
Petrolatum	Beeswax	Talc	TFE
Waxes	Lard Oil	Teflon	Other Resins
Greases	Fish Oil	Carbon	
	Soap	Tungsten Disulfide	
Vegetable	Synthetic		
Caster Oil	Oils		
Palm Oil	Waxes		
Cottonseed Oil	Fluorolubes		
Linseed Oil	Silicones		
Carnauba Wax			

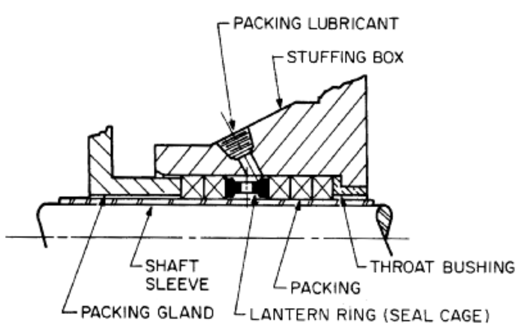

FIGURE 2 Common packing arrangement

The packing size for an existing piece of equipment can be found by using the formula:

$$\text{Packing size} = \frac{\text{box ID} - \text{shaft or sleeve OD}}{2}$$

TABLE 3 Packing sizes for rotating shafts

Shaft (or sleeve) Diameter, in (mm)	Packing size, in (mm)
$\frac{5}{8}$ to $1\frac{1}{8}$ (15 to 30)	$\frac{1}{4}$ (6.3)
$1\frac{1}{8}$ to $1\frac{7}{8}$ (30 to 50)	$\frac{5}{16}$ (8)
$1\frac{7}{8}$ to 3 (50 to 75)	$\frac{3}{8}$ (10)
3 to $4\frac{3}{4}$ (75 to 120)	$\frac{1}{2}$ (12.5)
$4\frac{3}{4}$ to 12 (120 to 305)	$\frac{5}{8}$ (16)

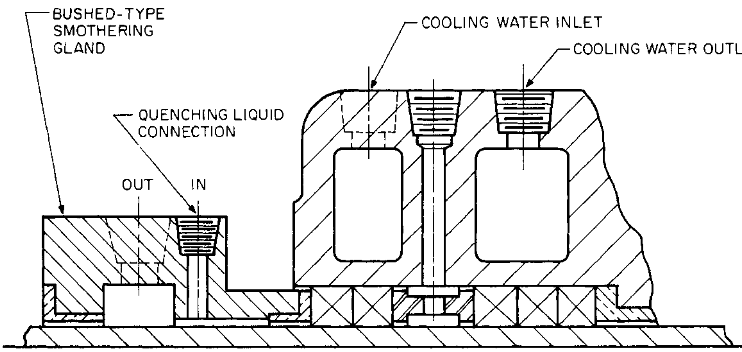

FIGURE 3 A smothering gland and water-cooled stuffing box

For packing to operate properly, the finish on the shaft sleeve must be at least 16 μin (0.4μm) centerline average (CLA) and the finish in the bore should be 63 μin (1.65 μm) CLA. The sleeve *must* be harder than the packing and chemically resistant to the liquid being sealed. If the sleeve has a coated material for a hard-wear surface, the sleeve must also have good thermal shock resistance.

Lantern Rings (Seal Cages) When an application requires that a lubricant be introduced to the packing, a lantern ring is used to distribute the flow (refer to Figure 2). This ring is used at or near the center of the packing installation. For ease of assembly, most lantern rings are axially split. The construction materials range from metal to TFE (tetrafluoroethlyene). TFE lantern rings are usually filled with glass or with glass and molybdenum disulfide. They are inherently self-lubricating and will not score the shaft. A throat bushing at the bottom of the stuffing box can be used to provide a closer clearance with the shaft to prevent packing extrusion.

Stuffing Box Gland Plates All mechanical packings are mechanically loaded in the axial direction by the stuffing box gland (refer to Figure 2). In cases where leakage of the process liquid is dangerous or can vaporize and create a hazard to operating personnel, a smothering gland is used to introduce a neutral liquid at lower temperatures (see Figure 3). A sufficient quantity of quenching liquid should be used to eliminate the danger from the liquid being pumped. The neutral liquid circulated in the gland mixes with the leakage and carries it to a safe place for disposal. Close clearances in the gland control the leakage of the combined liquids to the atmosphere. This quench can also be used to protect the packing from any wear through abrasion, because the leakage cannot vaporize and leave behind abrasive crystals.

TABLE 4 Leakage to prevent packing burning and sleeve scoring

Pressure lb/in^2 (bar)	Leakage, drops/min	cc/min
0–60 (0–4.0)	60	4
61–100 (4.1–6.8)		190
101–250 (6.9–17)		470

TABLE 5 Typically coefficients of friction

Material	*f*
Plain cotton	0.22
TFE impregnated fiber	0.17
Grease-lube fiber	0.10
Flexible graphite	0.05

Glands are usually made of bronze, but cast iron or steel can be used for all-iron pumps. When iron or steel glands are used, they are normally bushed with a non-sparking material like bronze.

Leakage and Power Consumption The basic operating parameters for compression packing are the PV (pressure × velocity) factor and the projected bearing area of the assembly. Together they determine the rate of heat generation for the system. Some leakage of the product being sealed or of the packing lubricant is necessary to keep the packing from burning up or scoring the shaft sleeve. The minimum values for leakage at different packing pressures are given in Table 4. Flexible graphite and carbon filament compression packings can be used with reduced leakage rates, or in dry, gas-tight pump stuffing boxes, as the developed heat is dissipated through the packing and pump housing.

The exact pressure P between the shaft sleeve and the packing is a function of the pressure distribution over the length of the packing and the axial loading from the gland. For ease of calculation when determining the PV value, the gage pressure of the liquid at the packing is multiplied by $\pi \times$ the packing ID $\times$ rpm. The heat generation at the packing can then be estimated as

$$Q = \frac{f\pi^2 PND^2 L}{CJ}$$

where Q = heat generated, Btu/min (W)
f = coefficient of friction
P = liquid pressure at packing, lb/in^2 gage (bar)
N = shaft speed, rpm
D = sleeve OD or packing ID, in (m)
L = sleeve length covered by packing, in (m)
C = 12 (60 for SI units)
J = mechanical equivalent of heat = 778 ft · lb/Btu (1 N · m/s · W)

The coefficient of friction for various packings at a pressure of 100 lb/in^2 (6.8 bar) is given in Table 5. The heat generated by the packing must be removed by the leakage through the packing.

APPLICATION INFORMATION AND SEALING ARRANGEMENTS

Materials of Construction Basically, stuffing box packing is a pressure breakdown device. In order for a packed stuffing box to operate properly, the correct packing must be

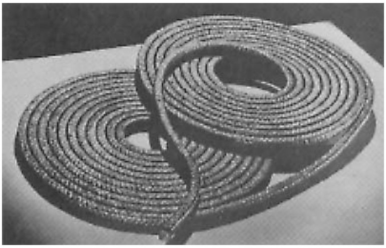

FIGURE 4 Graphite acrylic packing in continuous form (John Crane Inc.)

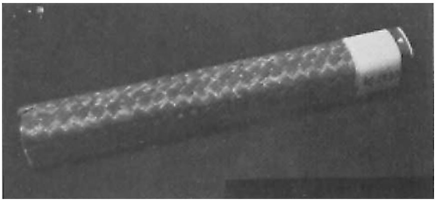

FIGURE 5 Non-asbestos packing (John Crane Inc.)

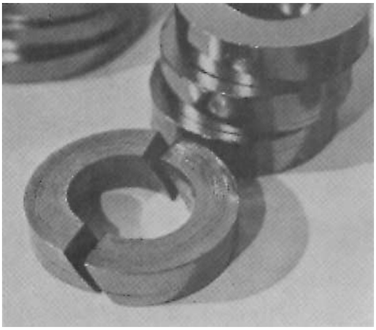

FIGURE 6 Flexible graphite packing rings (John Crane, Inc.)

applied and the appropriate design features must be included in the system. Numerous types of packing materials are available, each is suited to a particular service. These may be grouped into three categories:

1. **Non-asbestos packing** Since asbestos is no longer available as a packing material, other types of packing material are being used. These include cotton, TFE filament, Aramid fiber, aromatic polyamides, graphite/carbon yarn, and flexible graphite. All of these materials, with the exception of flexible graphite, can be impregnated with various lubricants. An example of graphited acrylic packing is shown in Figure 4. With the exception of flexible graphite, all the materials are of an interlaced construction for greater flexibility (see Figure 5). Packing made with this type of construction remains intact even if individual yarns wear away at the inside diameter of the packing.
2. **Flexible graphite** These types of packing rings were originally available cut from laminated sheet stock that required the rings to be made with an interference fit. Flexible graphite rings are made today from ribbon tape that is easily compressed to the shaft and bore to affect a better seal. Flexible graphite rings are available in split or endless rings (see Figure 6) or as the ribbon tape itself for ease of maintenance and installation. Operating limits for non-asbestos packings are found in Table 6.
3. **Metallic packing** The basic materials of construction are lead or babbit, aluminum, and copper in either wire or foil form. Metallic packing rings have flexible cores of non-asbestos materials such as twisted glass fiber. The packing is impregnated with graphite grease and/or oil lubricants (see Figures 7 and 8). Babbit is used in water and oil services at temperatures up to 450°F (229°C) and pressures up to 250 lb/in^2 (17 bar). Copper foil is used with water and low sulfur oils. Aluminum

TABLE 6 Service limitations of common packing materials[a]

Packing Material	Pressure (max.)[b] lb/in² gage (bar)	PV rating (max.)[c] lb/in² gage · fpm (bar · m/s)	Temp. (max)[d] °F (°C)	pH Range	Comments
Cotton	100 (6.8)		150(65.6)	5–7	Non-abrasive material; for cold water and dilute salt solutions
Flax/ramie	100 (6.8)	188,000 (65.8)	150 (65.6)	5–7	High, wet strength and excellent resistance to fungi and rotting; for cold water and dilute salt solutions
Plastic	100 (6.8) 250 (17)	188,000 (65.8) 471,000 (165)	600 (315.5) 150 (65.6)	4–8	Excellent sealing qualities, reacts well to gland adjustments, can extrude at higher pressure if not backed up by braided or metallic packing
Graphited acrylic	250 (17)	471,000 (165)	350 (175)	4–8	For mild chemicals and solvents
Acrylic TFE-impregnated	250 (17)	471,000 (165)	350 (175)	2–10	For mild chemicals and solvents
Babbitt (lead)	250 (17)	471,000 (165)	450(232.2)	2–10	Shaft sleeve must have a Brinell hardness of 500 or more; for hot oils and boiler feed water
Aluminum or copper	250 (17)	471,000 (165)	750 (398.8)	3–10	Shaft sleeve must have a Brinell hardness of 500 or more; for hot oils and boiler feed water
TFE filament	250 (17)	471,000 (165)	500 (260)	0–14	For corrosive liquids and food service; usually requires slightly higher break-in leakage
Aramid fiber	250 (17)	471,000 (165)	500 (260)	3–11	Strong resilient packing; maximum speed 1,900 fpm (9.6 m/s); good in abrasives and chemicals
Graphite/carbon filament[e]	250 (17)	471,000 (165)	750 (398.8)	0–14	For corrosive liquids and high- temperature applications
Flexible Graphite[f]	250 (17)	471,000 (165)	1000 (540)	0–14	Excellent conductor of heat from the sealing surfaces; operates with minimum leakage; excellent radiation resistance

(a) Continuous lubrication introduced at the lantern ring. This table is only a guide. Consult the packing manufacturer with complete operating conditions for exact recommendations.

(b) Pressure relates to the operating pressure at the stuffing box.

(c) PV data based on a 2 in (5.08 cm) shaft at 1,750 and 3,600 rpm.

(d) Temperature is the product temperature.

(e) Functional temperature. Graphite can be used up to 3000°F (1650°C) in non-oxidizing atmospheres.

(f) Functional temperature. Flexible graphite can be used to 5300°F (2970°C) in non-oxidizing atmospheres.

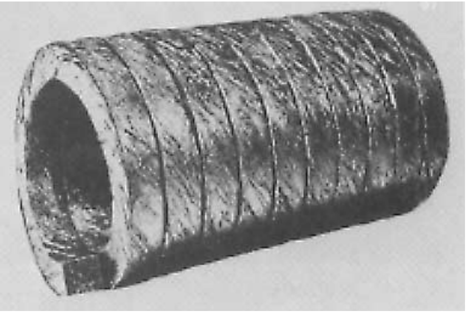

FIGURE 7 Metallic packing in spiral form (John Crane Inc.)

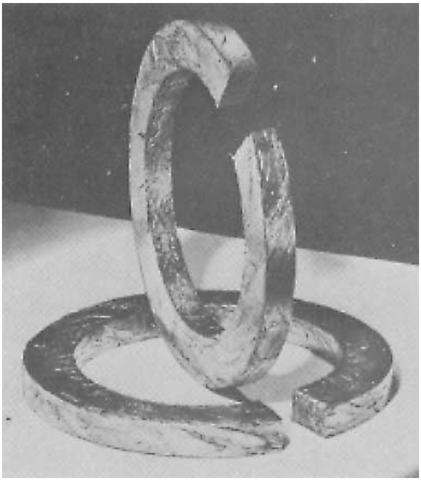

FIGURE 8 Metallic packing in ring form (John Crane Inc.)

is used in oil service and heat transfer fluids. Both copper and aluminum have a temperature range up to 1000°F (537°C) and pressures of 250 lb/in^2 (17 bar). Babbit is not suitable for running against brass or bronze shaft sleeves, and where copper or aluminum is used, the sleeves should be 550 Brinell (55–60 Rockwell C) or harder.

Additional service limitations for common packing materials can be found in Table 6.

ENVIRONMENTAL LIMITATIONS

Pressure Every pumping application results in either positive or negative pressure at the throat of the pump stuffing box. A positive pressure will force the liquid pumped through the packing to the atmosphere side of the pump. Higher pressure will result in greater leakage from the pump. This results in excessive tightening of the gland, which causes accelerated wear of the shaft or shaft sleeve and packing. For pressures at the stuffing box greater than 75 lb/in^2 (5.1 bar), some means of throttling the pressure should be considered. A combination of hard and soft rings die-formed to the exact stuffing box bore

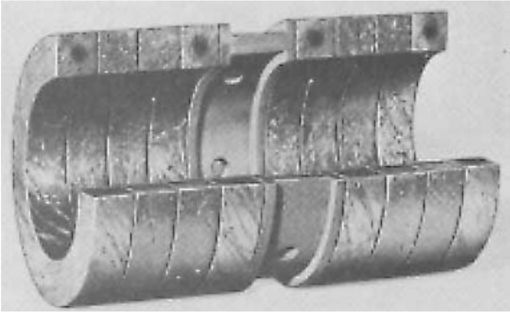

FIGURE 9 Combination of hard and soft packing (John Crane Inc.)

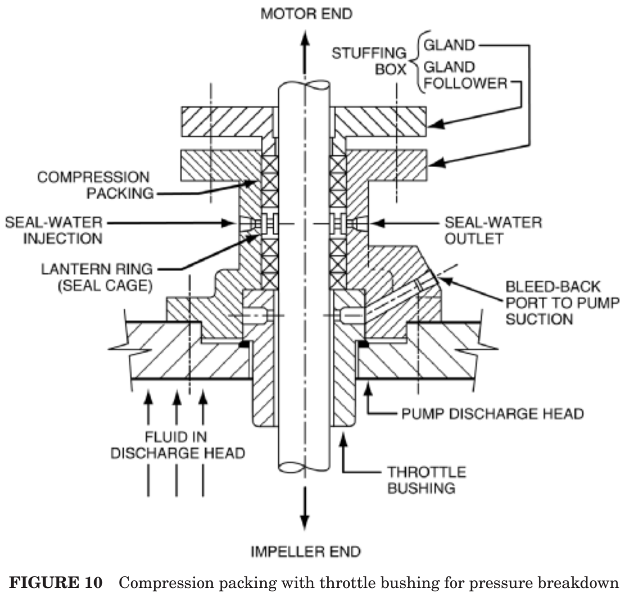

FIGURE 10 Compression packing with throttle bushing for pressure breakdown

and sleeve dimensions can be used (see Figure 9). Harder rings at the inboard end of the box and at the lantern ring and gland break down the pressure and prevent the extrusion of the packing.

If the packing itself cannot be used to break down the pressure, then a throttle bushing must be used (see Figure 10). This is a typical arrangement for a vertical turbine pump where the stuffing box is subject to the discharge pressure of the pump. Here the throttle bushing is used to bring the liquid to almost suction pressure, and most of the leakage through the bushing is bled back to the suction. When the suction pressure is less than atmospheric, as in condensate pump service, an orifice is used in the piping back to the suction in order to maintain pressure above atmospheric pressure in the stuffing box. This prevents air leakage into the pump and excessive flow and wear at the bushing.

When a pump is fitted with a bypass line from the discharge, a valve can also be used to reduce the pressure at the stuffing box. This is another method for reducing pressure for the benefit of the installation.

Air Leakage When the pressure at the stuffing box is atmospheric or just below during normal operation, a bypass from the pump casing discharge through an orifice can be used to inject liquid into the lantern ring. The sealing liquid will flow partly into the pump and partly out to the atmosphere, thereby preventing air from entering at the stuffing box. This arrangement is commonly used to handle clean, cool water. In some pumps, these connections are arranged so that liquid can be introduced into the lantern ring through internally drilled passages.

When the negative pressure is very low, such as when the suction lift is in excess of 15 ft (4.6 m), an independent injection of 10 to 25 lb/in^2 (4.8 to 11.7 bar) higher than the atmospheric pressure must be used on the pump. Otherwise, priming may be difficult. Hot well pumps or condensate pumps operate with as much as 28 in (0.7 m) of vacuum, and air leakage into the pump would occur even on standby service. Here a continuous injection of clean, cool water is required, or alternatively, a cross connection of sealing water to another operating pump will provide sealing pressure as long as one pump is operating. A lantern ring is provided for this, as shown in Figure 10.

Temperature The control of temperature at the stuffing box is an important factor in promoting the life of the packing. Even though packings are rated for high product temperatures, cooling in most cases is desirable. The heat developed at the packing must also be removed. The rules of thumb are as follows:

- For light service conditions with pressures at 15 lb/in^2 (1 bar) and temperatures at 200°F (90°C), cooling is desirable.
- For medium service conditions with pressures at 50 lb/in^2 (3.4 bar) and temperatures at 250°F (118°C), lantern ring cooling is desirable, such as one gpm (3.78 l/min) at 5 lb/in^2 (0.34 bar) above process pressure.
- For high service conditions with pressures at 100 lb/in^2 (6.8 bar) and temperatures at 300°F (131°C), lantern ring cooling is desirable, such as one gpm (3.78 l/min) at 5 lb/in^2 (0.34 bar) above process pressure plus a water-cooled stuffing box (refer to Figure 3).

When cooling water is required, it is circulated through the stuffing box at the lantern ring. For horizontal-shaft pumps, the inlet should be at the bottom, with the outlet at the top of the stuffing box. Some of the coolant may flow to the process liquid and some to the atmosphere. The outboard packing rings seal only the cool liquid.

If the product to be sealed will solidify, then the packing box will have to be heated before the pump is started. This can be accomplished by steam or electric tracing of the pump stuffing box.

Abrasives Liquids that contain abrasives in the form of *suspended solids* such as sand and dirt will shorten the life of the packing. Particles will imbed themselves in the packing and will begin to wear the shaft or shaft sleeve. Abrasives can be eliminated at the sealing surfaces by injecting a clean liquid into the lantern ring. The injection may take the form of a bypass line from the pump discharge through a filter or centrifugal separator. Where necessary, the clean injection may also be from an external source.

To keep the abrasives from the packing in horizontal-shaft pumps, the injection can be made directly to the inboard end of the stuffing box through the lantern ring (see Figure 11). A soft rubber gasket between the lantern ring and the box shoulder can be used to limit the flow of clean liquid and the ingress of abrasives.

When separators and filters cannot be used, an injection from an external source must be considered. Two rings of packing are located between the lantern ring and the inboard end of the stuffing box to keep the product dilution to a minimum. External flushing should be injected into the stuffing box at a pressure 10 to 25 lb/in^2 (1.7 bar) greater than the pressure at the inboard end of the box from the liquid being pumped. A regulating valve, illustrated in Figure 12, can be used to control the pressure and flow to the packing installation. Flow to the packing can be regulated to ensure the best operating environment for this seal, while conserving water used for injection.

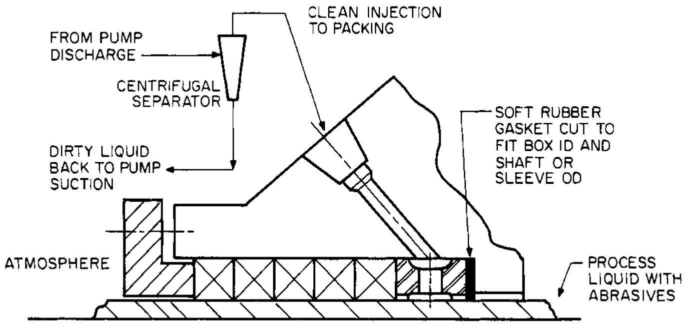

FIGURE 11 A clean injection through a centrifugal separator to keep abrasives out of the stuffing box

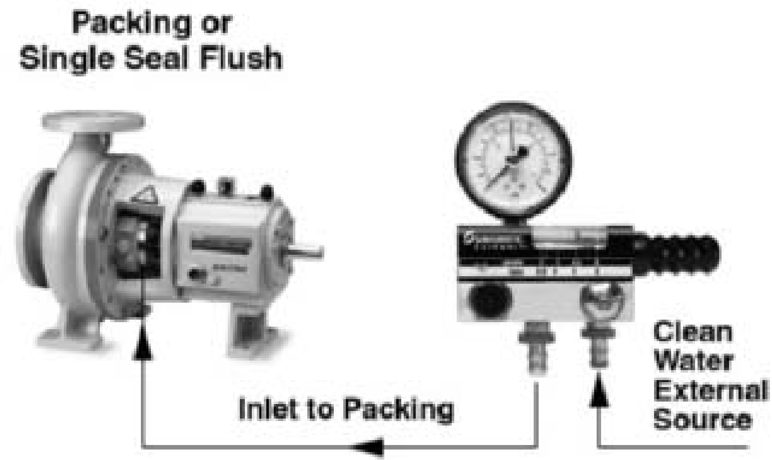

FIGURE 12 A regulation valve that controls and monitors the flow of water to the packing (Safematic)

Dissolved solids in the liquid being pumped can also create a wear problem. Here an increase or decrease in stuffing box temperatures may be necessary to keep solids in solution.

INSTALLING CONTINUOUS COIL PACKING

To install continuous coil packing, perform the following steps:

1. Loosen and remove the gland from the stuffing box.
2. Using a packing puller, begin to remove the old packing rings.
3. Remove the split lantern ring (if present) and then continue removing the packing with the puller.
4. After the packing has been removed, check the sleeve for scoring and nicks. If the shaft sleeve or shaft cannot be cleaned up, it must be replaced. Check the size of the

stuffing box bore and the shaft sleeve or shaft diameter to determine which size packing should be used.

5. After the size of the packing has been determined, wrap the packing tightly around a mandrel, which should be the same size as the pump shaft or sleeve. The number of coils should be sufficient to fill the stuffing box. Cut the packing along one side to form the individual rings.
6. Before beginning the assembly of any packing material, be sure to read all the instructions from the manufacturer. Assemble the split packing rings on the pump. Each ring should be sealed individually with the split ends staggered 90° and the gland tightened to seal and fully compress the ring. Be sure the lantern ring is reinstalled correctly at the flush connection. Then back off the gland and retighten it, but only finger-tight. The exception to this procedure is that TFE packing should be installed one ring at a time, but not seated because TFE packings have high thermal expansion.
7. Allow excess leakage during break-in to avoid the possibility of rapid expansion of the packing, which could score the shaft sleeve or shaft so that leakage could not be controlled.
8. Leakage should be generous upon startup. If the packing begins to overheat at startup, stop the pump and loosen the packing until leakage is obtained. Restart only if the packing is leaking.

CAUSES FOR A SHORT PACKING LIFE

In order for packing to operate properly, the equipment must be in good condition. Shafts should be checked for runout and eccentricity to be sure they are within the manufacturer's recommended tolerances. Surfaces in contact with the packing should be finished to the correct smoothness and tolerance. Table 7 lists common troubles that affect the packing life. Causes and possible cures are also given.

TABLE 7 Packing troubles, causes, and cures

Trouble	Cause	Cure
No liquid delivered by pump	Lack of prime (packing loose or defective, to allowing air leak into suction)	Tighten or replace packing and prime pump.
Not enough liquid delivered by pump	Air leaking into stuffing box	Check for leakage through stuffing box while operating. If no leakage occurs after after reasonable gland adjustment, new packing may be needed. or Lantern ring may be clogged or displaced and may need centering in line with sealing liquid connection. or Sealing liquid line may be clogged. or Shaft or shaft sleeve beneath packing may be badly scored, allowing air to be sucked into pump.
	Defective packing	Replace packing and check the smoothness of the shaft or shaft sleeve.
Not enough pump pressure	Defective packing	As per preceding
Pump works for a while and then quits	Air leaks into stuffing box	As per preceding
Pump takes too much power	Packing too tight	Release gland pressure and retighten reasonably. Keep leakage flowing. If none, check packing, sleeve, or shaft.
Pump leaks excessively at stuffing	Defective packing	Replace worn packing or replace packing damaged by lack of lubrication.
	Wrong type of packing	Replace packing not properly installed or run in. Replace improper packing with correct grade for liquid being handled.
	Shaft or shaft sleeve scored	Put in lathe and machine-true and smooth or replace. Recheck dimensions for correct packing size.
Stuffing box overheats	Packing too tight	Release gland pressure and retighten.
	Packing not lubricated	Release gland pressure and replace all packing if any burnt or damaged.
	Wrong grade of packing	Check with pump or packing manufacturer for correct grade.
	Insufficient cooling water to jacket	Check for open supply line valve or clogged line.
	Stuffing box improperly packed	Repack.
Packing wears too fast	Shaft or shaft sleeve worn or scored	Remachine or replace.
	Insufficient or no lubrication	Repack, making sure packing is loose enough to allow some leakage.
	Packing packed improperly	Repack properly, making sure all old packing is removed and the box is clean.
	Wrong grade of packing	Check with pump or packing manufacturer.
	Pulsating pressure on external seal liquid line	Remove cause of pulsation.

FURTHER READING

Berzinsa, A. "Finer Points of Compression Packing Help with Centrifugal Pumps," *Power*, June 1974, pp. 58–59.

Ciffone, J. G. "Packing," John Crane Mechanical Maintenance Training Center, Morton Grove, Illinois, November 1994.

Crane Packing Company. *Engineering Fluids Sealing, Materials, Design and Applications: An Information Compendium of Technical Papers*. Morton Grove, IL 1979.

Elonka, S. "Packing: Power Practical Manual," *Power*, March 1955, pp. 107–130.

Krisle, O.M. "How to Get Longer Life out of Pump Packing and Shaft Sleeve," *Water and Sewage Works*, June 1967, pp. 199–201.

Neale, M.J., "Packing Glands," *Tribology Handbook* (Sec. A36), Wiley, New York; 1973.