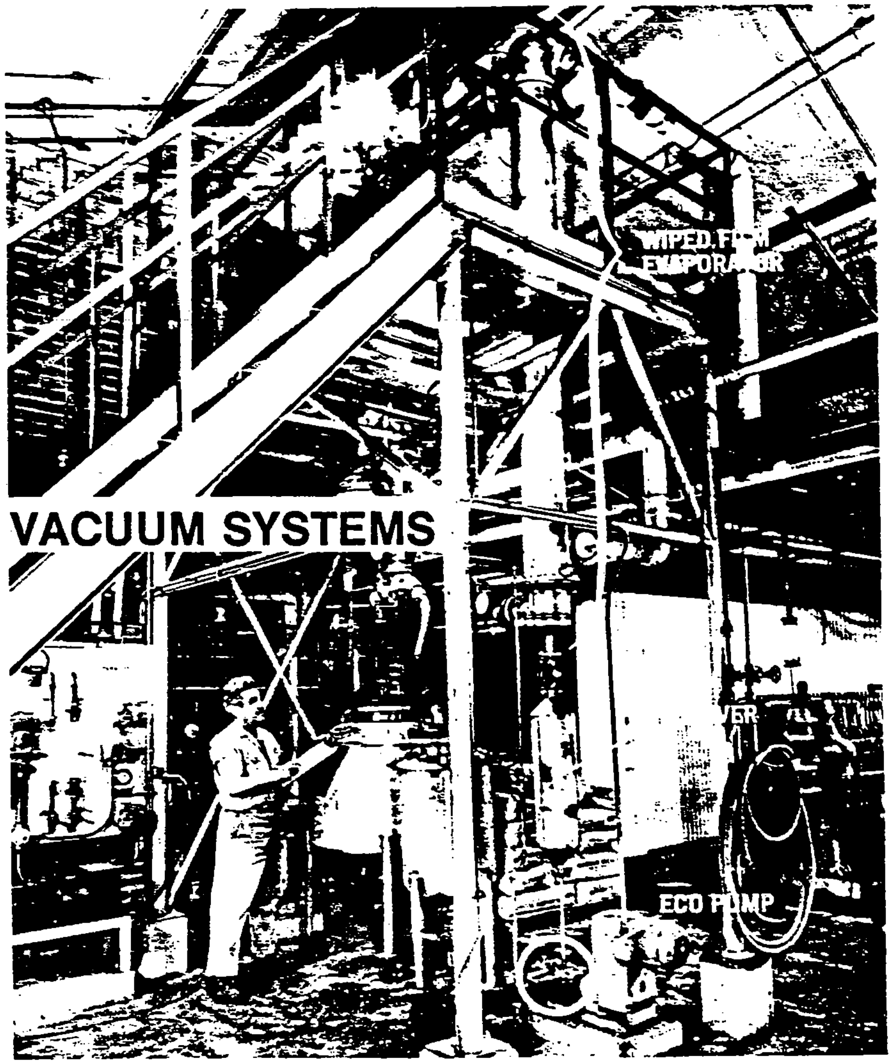
ECO®

Technical Paper 77-1

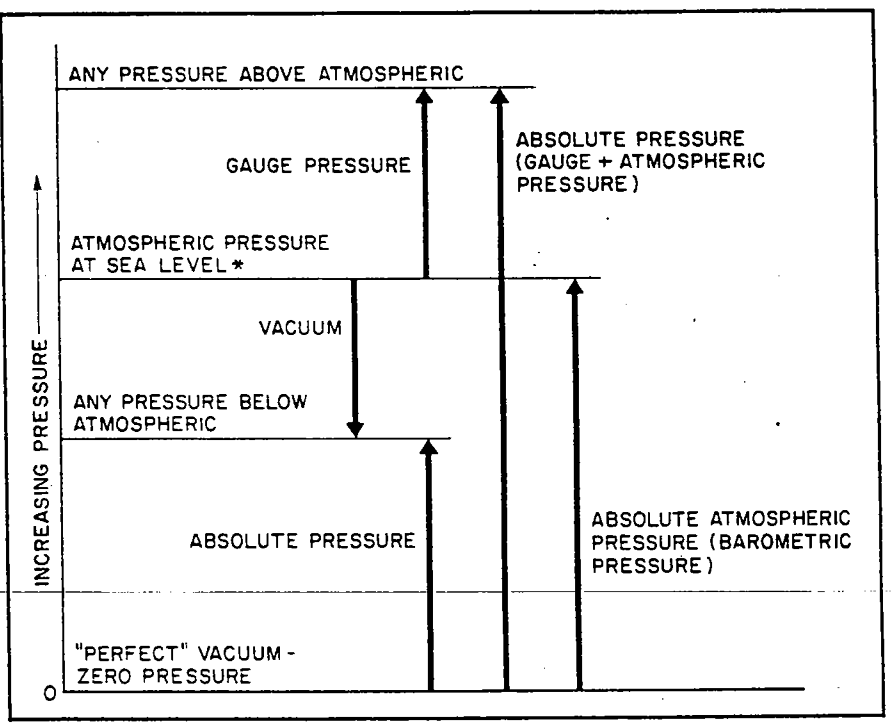
SMALL PUMPS IN VACUUM SYSTEMS



Generally when one associates pumps and vacuum systems, the first thing that comes to mind is a pump to produce the vacuum. In a continuous vacuum processing operation, there is also a need for pumps to feed the system and to remove products from it, all the while maintaining the integrity of the vacuum system itself. This discussion will deal with the use of small rotary gear pumps to transfer fluids from atmospheric pressures into vacuums, or from vacuum to atmospheric pressure, as well as to continuously circulate liquids in closed systems under equal or differential negative pressures.

What is Vacuum

The term vacuum is used to designate any pressure less than atmospheric. A "perfect" vacuum means a total absence of any pressure at all, and in practice cannot



*Atmospheric pressure at sea level varies with weather. The "standard" value is 760 millimeters of mercury (14.696 pounds per square inch).

be achieved. A "perfect" vacuum does not exist even in outer space where there is some pressure, however minute.

Pressure is equal to force per unit area, and the internationally accepted unit of pressure is the pascal. One pascal equals the force of one newton acting on an area of one square meter, and the newton is the force required to accelerate one kilogram by one meter per second per second.

In practical terms, the numerical value of the pascal is very small, so the kilopascal (kPa) is more useful. 100 kPa are about equal to atmospheric pressure at sea level.

Commonly used units of pressure in the English system are pounds per square inch (psi) and feet of water. When working with vacuums —pressures less than atmospheric— inches or millimeters of mercury are often used, and unfortunately confusion often develops. When a pressure is given as 10 millimeters of mercury, it must be specified as "10 mmHg absolute" or "10 mmHg vacuum". Ten millimeters absolute is ten millimeters above complete vacuum, whereas ten millimeters vacuum is ten millimeters below atmospheric. Atmospheric pressure at sea level is generally taken to be 760 millimeters of mercury, so there is a difference of 740 millimeters between the two values given. Only at the half way point, when the pressure is 380 mmHg, can the terms "absolute" or "vacuum" be omitted without confusion. The same is true whenever pressure is expressed as the equivalent height of a column of liquid — inches of mercury, inches of water, feet of water, etc.

Confusion can also be avoided by using the abbreviation psia or pounds per square inch absolute. Zero psia indicates a complete absence of pressure, or absolute vac-

TABLE I — PRESSURE EQUIVALENTS

	kPa	PSI	Kg/cm^2	mmHg	in.Hg	Ft. H_2O	Atm
1 Kilopascal =	1	.145	.01	7.5	.295	.335	.0099
1 Pound per square inch =	6.895	1	.07	51.7	2.04	2.31	.068
1 Kilogram per square centimeter =	98	14.2	1	735.56	28.96	32.8	.968
1 Millimeter of mercury =	.133	.019	.00136	1	.039	.045	.0013
1 Inch of mercury =	3.39	.49	.0345	25.4	1	1.134	.033
1 Foot of water =	2.99	.433	.03	22.4	.88	1	.029
1 Atmosphere =	101	14.696	1.033	760.	29.9	33.9	1

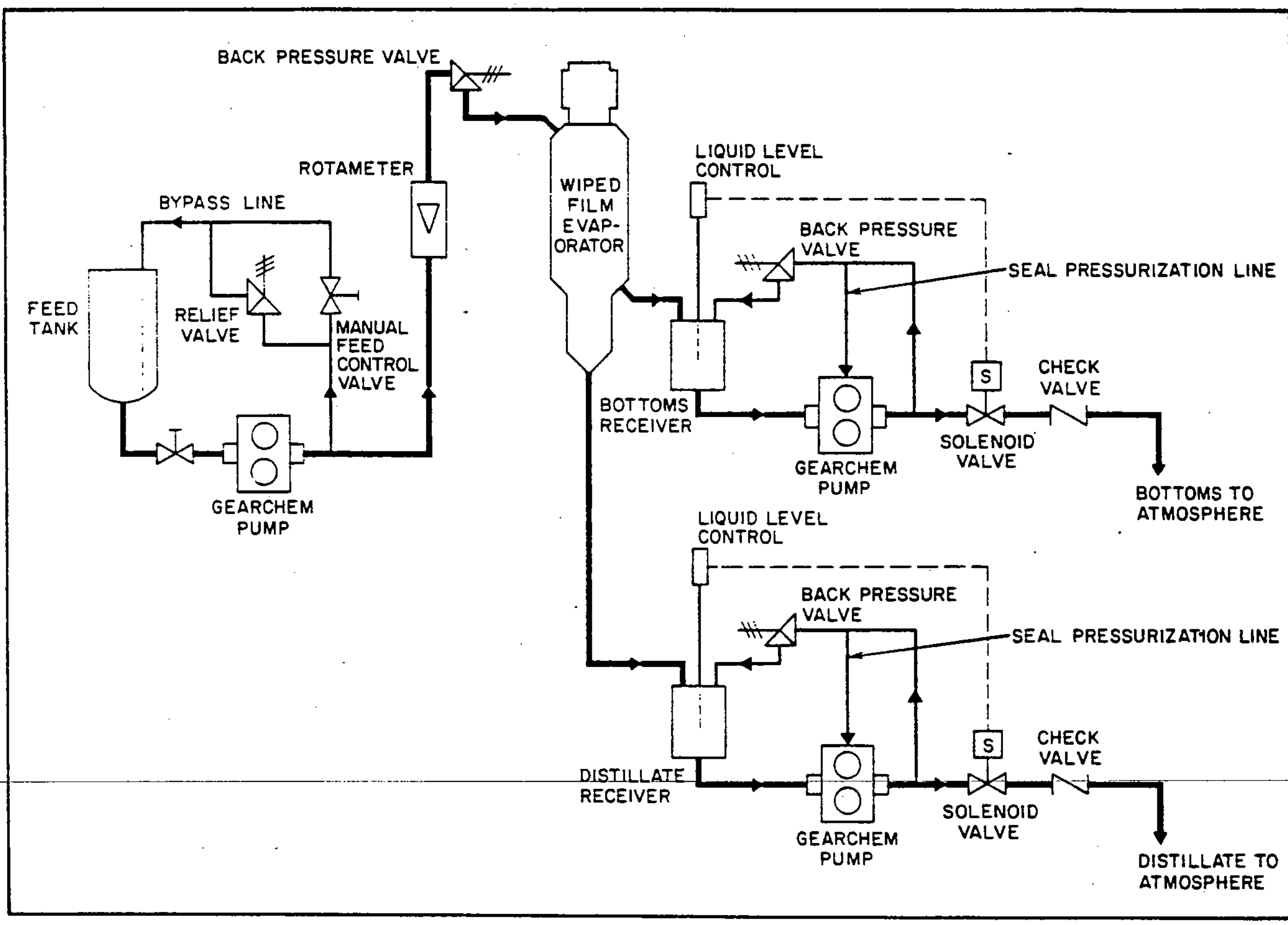


FIGURE 1. *Typical vacuum distillation system using a wiped film evaporator with internal condenser. Feed pump is equipped with a single internal mechanical seal while distillate and bottoms pumps are fitted with the external seal for vacuum service.*

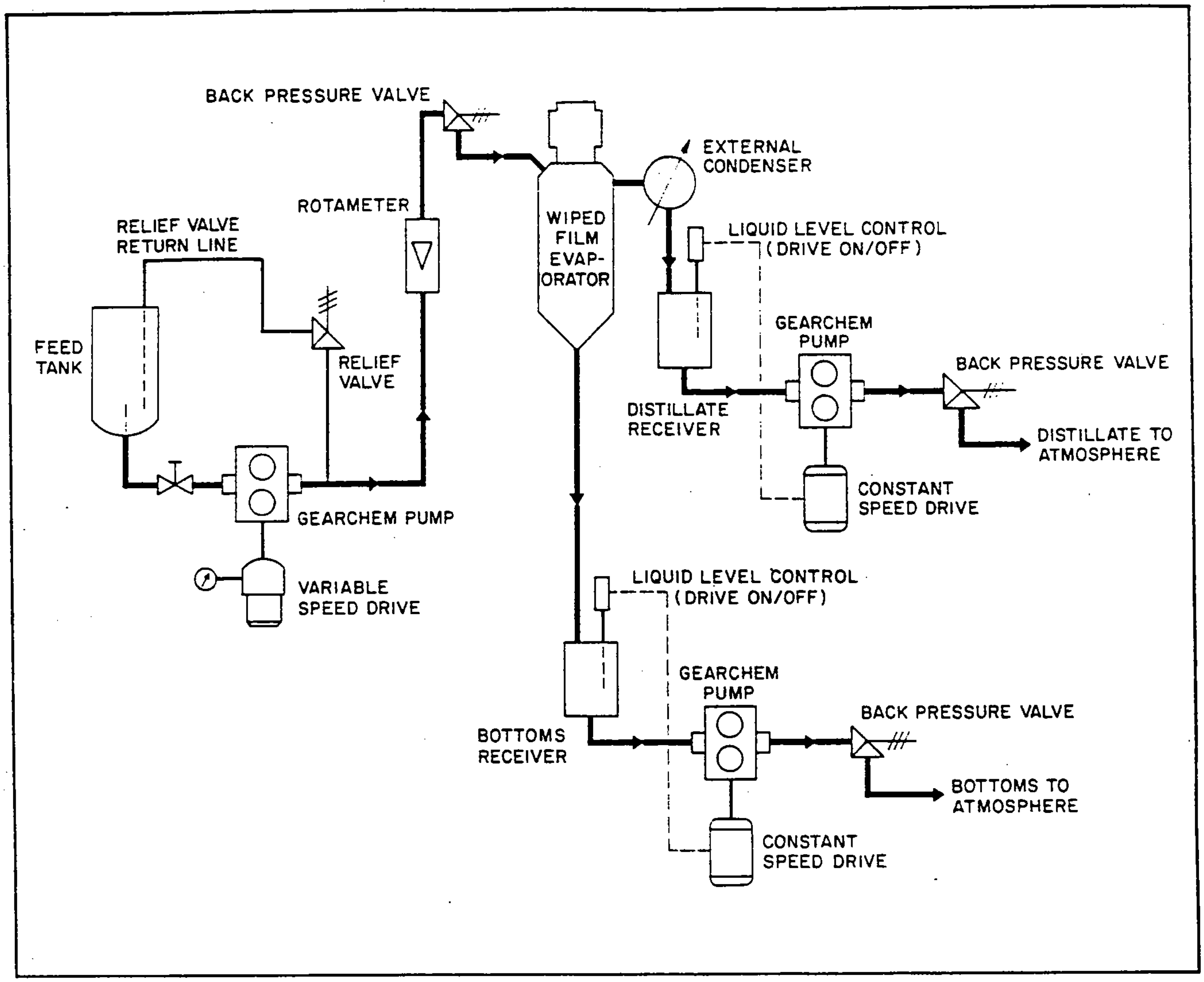


FIGURE 2. *Another typical system using variable speed drive on the feed pump and ON OFF control of distillate and bottoms pumps. Latter are equipped with double mechanical seals.*

uum. 14.7 psia is generally accepted as atmospheric pressure at sea level. Most pressure gauges do not have compensating chambers to counterbalance the existing absolute pressure at sea level and so read "zero" when not under a pressure higher than atmospheric. Hence zero gauge pressure (0 psig) is equal to 14.7 psia.

Chart I shows the relationships between gauge and absolute pressures while Table I is a comparison of commonly used pressure measurement units.

Uses of Vacuum

Processing operations are conducted at subatmospheric pressures — vacuum — for a number of reasons. For instance, vacuum distillation, evaporation, filtration, crystallization, degasification and other types of vacuum processing are used where high temperatures would degrade the product, where only low temperature heat sources are available, or where residual heat or heat of reaction is the only heating permitted or available. Both pressure and temperature can be closely controlled in vacuum separation processes making it possible to maintain or improve product quality and to achieve rigorous product specifications that could not be obtained in any other manner.

Where Gear Pumps Fit In

Eco Gearchem pumps find application primarily as feed pumps, distillate pumps and bottoms pumps. Figure 1 shows a system of three pumps with a wiped film evaporator containing a built-in condenser. The discharge flow rates of distillate and bottoms are controlled using by-pass recirculation of pump outputs together with liquid level controls on distillate and bottoms receivers. Figure 2 shows a similar system of three pumps with an external condenser-equipped evaporator but in this case, the materials being processed do not permit by-pass recirculation and control of flow is by level control in the receiver, with the pumps operating cyclically.

Isolation of the feed pump side is by means of the back pressure valve in the pump discharge line. This valve prevents feed material from being "sucked" into the vacuum system and presents a constant pressure to the feed pump, assuring metering accuracy.

Isolation of the distillate and bottom sides is by means of a check valve in the discharge line of each pump. To form an effective pressure seal, it is recommended that the check valves be of "soft" seat design.

Pump Shaft Seals

Assuming tight static connections, the only areas left that might present a leakage path from atmosphere into the vacuum system are along the drive shafts of the bottoms and distillate pumps.

In Figure 1, the pumps are equipped with the Eco external mechanical seal for vacuum service. The system is shown in more detail in Figure 3 and a cutaway view appears in Figure 4.

The pump operates continuously, recirculating fluid in the receiver through the back pressure valve. A line is connected from the discharge side of the pump, upstream from the back pressure valve, to the mechanical seal extension, thereby pressurizing the pump side of the mechanical seal at a value equal to the pressure existing in the discharge loop. Pressure in this loop must be higher than atmospheric so there can be no possible ingress of air through the external shaft seal.

When the solenoid valve is closed, and there is no discharge to atmosphere, the pressure in this loop is equivalent to the pressure setting of the back pressure valve. When the solenoid is open, loop pressure is determined by the pressure drop across the solenoid valve and the discharge check valve. Size the solenoid and check valves and set the back pressure valve such that seal pressurization levels range between 25 and 30 psig when the solenoid is open and the pump is discharging to atmosphere (emptying the receiver). The level control opens the solenoid valve at high level and closes it at low level so the pump does not run dry.

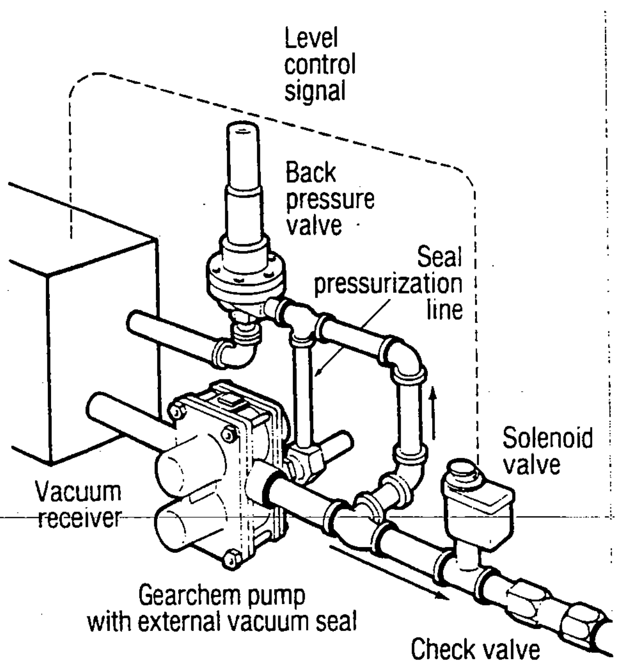
The use of the Gearchem pump equipped with the external seal for vacuum service avoids the necessity of providing for a separate flush required for the double mechanical seal. However, discharge pressures of pumps equipped with external mechanical seals are limited to 50 psig maximum.

Double mechanically sealed pumps are used in the bottoms and distillate sections of the system shown in Figure 2. Any ingress of air along the shaft is prevented by the separate seal flush stream, which must be at a pressure at least 25 to 30 psig. Details of the double mechanical seal are shown in Figures 5 and 6. This type of seal can handle pressures up to 100 psig.

Selecting the Pump and Drive

Several criteria govern pump selection in vacuum systems and these of course include the chemical characteristics of the fluid pumped, required flow rates and pressures. Fluid viscosities in different vacuum systems can range from water-thin fluids to sticky, tar-like materials, and in some applications, viscosities can vary widely within the same system.

Another common characteristic



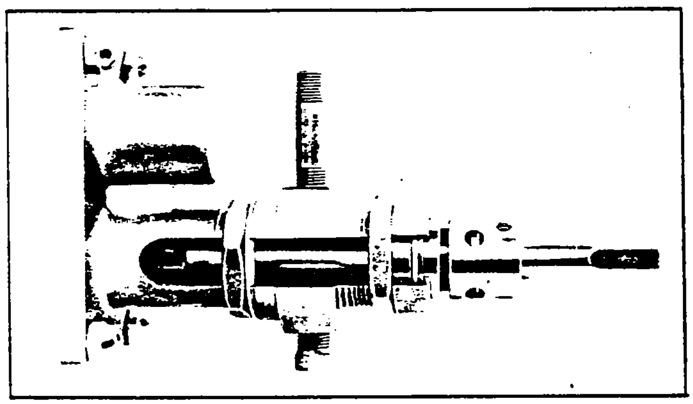
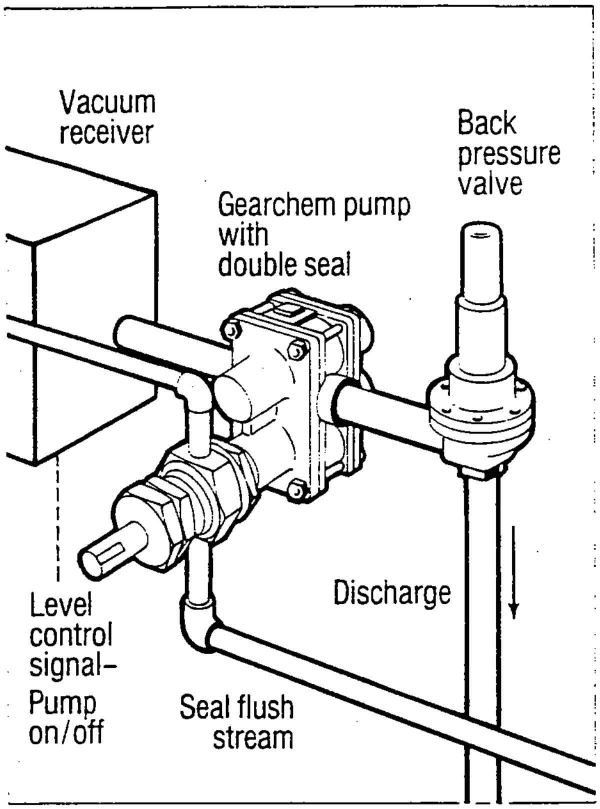


FIGURE 4. *Cutaway view of external seal for vacuum service. Mechanical seal head itself is on right and rotates with shaft. Pressurization line from pump discharge connects to nipple to maintain higher-than-atmospheric pressure in seal housing to prevent ingress of air along seal mating surfaces.*

FIGURE 3. *Isometric rendering of Gearchem pump with external seal for vacuum service showing seal pressurization line from pump discharge into seal housing extension.*



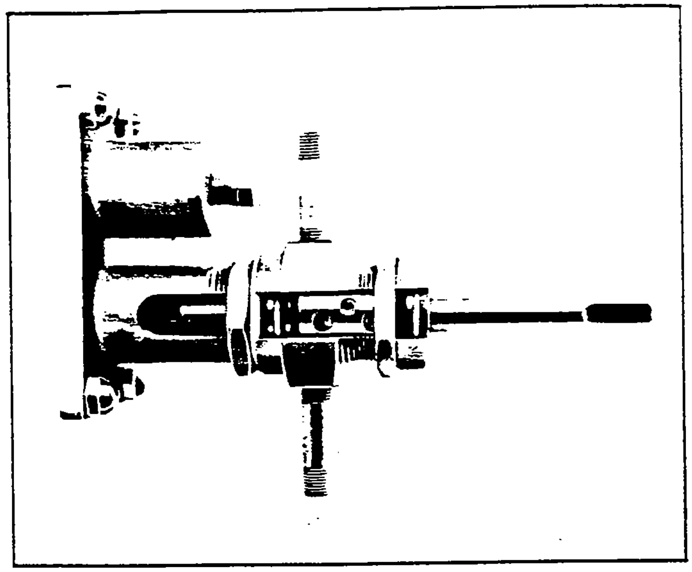


FIGURE 6. *Double mechanical seal configuration requires flush stream in and out of seal housing to cool and lubricate seal mating faces. By maintaining seal flush stream, vacuum integrity of system is assured even when pump is not running.*

FIGURE 5. *Isometric view of typical double-seal-fitted Gearchem pump.*

in vacuum processing is erratic or sporadic flows of distillate and bottoms to the respective pumps. Methods must be found to avoid starving pump suction under these low flow, or interrupted flow, conditions. For this reason, receivers are always recommended.

Materials of construction for pump housings and shafts are selected as in non-vacuum applications — to provide maximum corrosion-resistance to the pumped fluid. Drive and idler gear choice depends on fluid viscosity and temperature as well as resistance to chemical attack. Where viscosities exceed 50 cps, two metallic gears are the best selection. With lower viscosities, a metallic drive gear and plastic idler gear can be used, provided temperatures do not exceed acceptable limits for plastic idlers and temperatures remain constant. Remember, plastics expand and contract considerably with temperatures, and gear binding or excessive pump slippage will occur at higher or lower temperatures than that for which the plastic gear is selected and sized.

Where viscosities are too low to permit a metallic idler gear, and temperatures are too high or vary, a carbon idler should be specified. It is dimensionally stable over a wide temperature range and can operate against a metallic driver in very thin as well as thick fluids.

In many instances, fluid temperatures at start up are quite low and product is therefore quite viscous. As operations continue, temperatures rise and viscosity decreases rapidly. These factors must be taken into consideration when selecting the right gear combination.

Choice of wearplates is largely dependent on temperature and chemical compatibility. Carbon is recommended wherever possible because of dimensional stability at elevated or fluctuating temperatures. Carbon is also an excellent wear-plate material with two metallic gears or with combination gears (metallic drive and plastic idler, or metallic drive and carbon idler).

Where carbon is not compatible with the system, filled TFE wearplates can be used but they are limited in temperature. Generally, a pump fitted with TFE wearplates should not be used above 150°F. In some applications where the fluid is both viscous and has good lubricating properties, and where pump speeds are low, ceramic wearplates are the answer.

Considerations in the choice of bearings are almost identical to those of wearplates. Carbon is the best material, with filled TFE bearings available for limited temperature operation.

In some stripping operations, where carbon might not be acceptable and TFE could be affected by fluorocarbon solvents or certain amines, phenolic wearplates and bearings are available, providing the system is totally anhydrous. Even very slight amounts of water will cause the phenolic to swell. As with TFE components, temperatures are limited to 150°F.

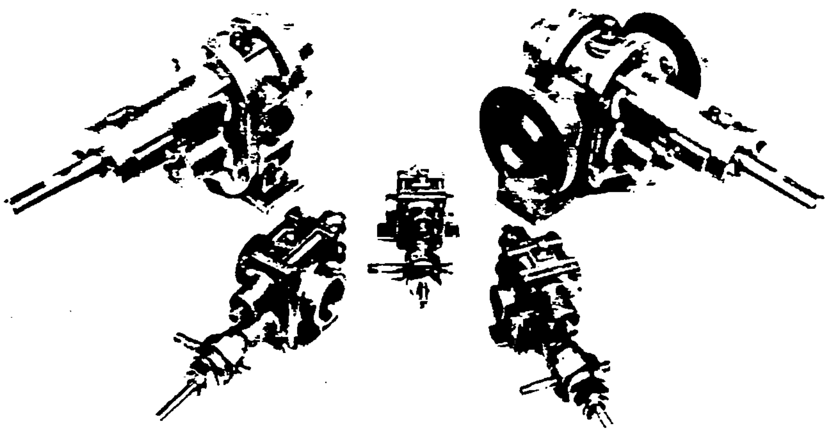


FIGURE 7. *Center housing vent ports, available with all Gearchem pumps, are recommended when pumped fluids are near their boiling points or contain excessive amounts of entrained gases.*

Housing Vents

All Gearchem pumps can be furnished with vent ports in the center housings to enable any gases or vapors to be bled off. The feature is particularly useful in vacuum applications where fluids are close to boiling at the temperatures and pressures involved. Use of the center housing vent can often save the considerable expense of changing out the pump driver from a higher to a lower speed machine in order to prevent vapor binding in the pump.

The vent connection is ⅛" NPT and the vent line can be returned to the receiver or the column, but must be laid out in such a manner as to avoid a trap. Where required, the vent line may be cooled to condense the vapors before returning them to the receiver or still. A throttling or stop valve can be fitted in the vent line for control purposes, but this is often not necessary provided the line is kept small.

Pump Jackets

Two-piece, bolt-on heating jackets are available for each size of Gearchem pump and this feature is often very useful in vacuum applications where close temperature control is imperative.

The interior of each jacket half is molded to conform closely to the contours of the pump and when the two halves are bolted together, the pump is completely surrounded. Heat transfer efficiency is greatly improved with the use of a plastic heat transfer compound between the pump and the jacket interior.

The heating medium can be steam (150 psig max.) or any of the organic heat transfer media. A braided, flexible metallic hose is provided to connect the two jacket halves, with heating fluid being brought to one jacket half and taken from the other.

These jackets can also be used to cool the pump, using water, brine or fluorocarbon refrigerants as the cooling media. When routine maintenance is required, the two jacket halves are separated, exposing the pump which can be easily disassembled.

Bearing Flush Ports

An optional feature that is available with all Gearchem pumps are bearing flush ports that allow rapid evacuation of material left in the pump without removing the pump from the system. This feature is important in vacuum processing operations where different products are handled and cross-contamination is to be avoided.

Bearing flush ports are ⅛" NPT pipe taps provided in both bearing hubs of the idler gear and in the bearing hub of the drive gear opposite the drive shaft extension. They are fitted with pipe plugs of the appropriate metallurgy when shipped from the factory.

High Temperature Shaft Sealing

As stated earlier, the external seal for vacuum service is limited to 50 psi differential pressure. There is also a temperature limitation imposed by the TFE secondary sealing member in the seal head of 177°C (350°F). The double mechanical seal can be used at higher fluid tem-

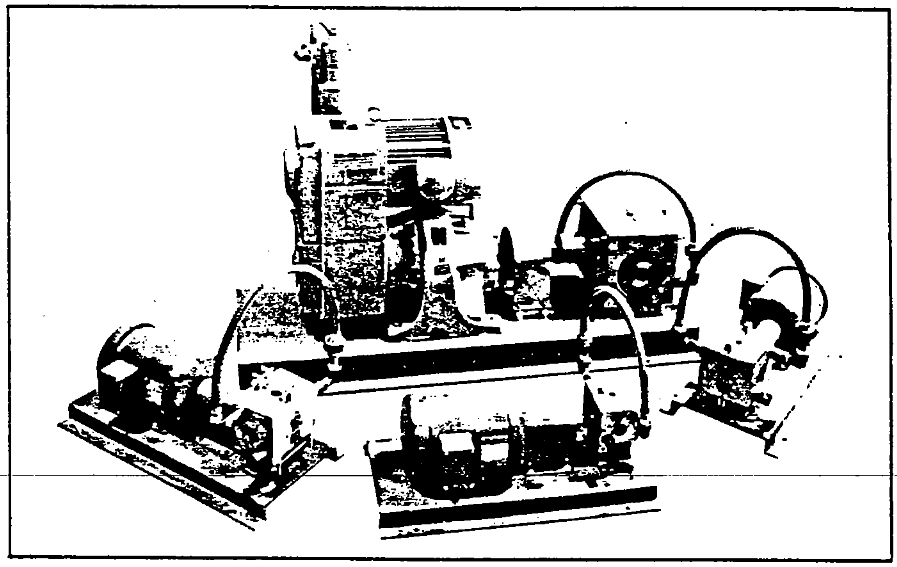


FIGURE 8. *Two-piece, bolt-on jackets completely surround the pump, providing close temperature control. Jackets can be supplied with new pumps or retrofitted to units already in the field.*

peratures, but is limited to 230°C (450°F).

At temperatures above these limits, a lantern ring stuffing box arrangement is necessary, using carbon/graphite packing rings and a pressurized flush through the lantern ring. This arrangement is particularly valuable when the product has some viscosity.

Submerged Pumps

Pumps equipped with external seals for vacuum service must run continuously in order to maintain higher-than-atmospheric pressure in the seal housing. Double mechanically sealed pumps can be started and stopped, but the seal flush system must operate continuously in order to maintain vacuum integrity.

In circumstances where the pump must operate cyclically but a separate flush stream is not available, the entire pump can be submerged as shown in Figure 9. The fluid surrounding the pump should have a sufficiently high viscosity to prevent ingress along the shaft sealing arrangement.

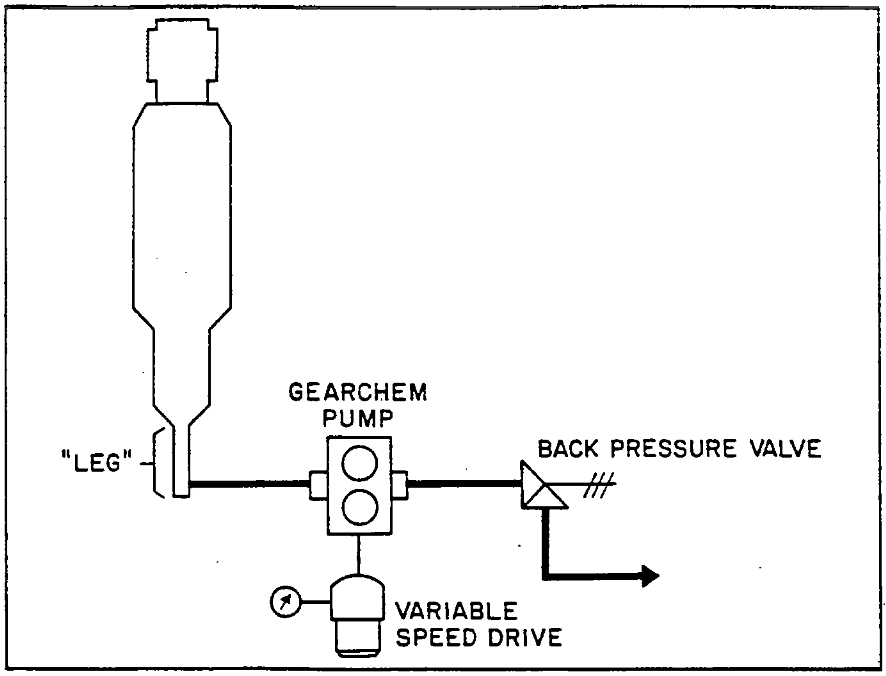


FIGURE 10. *Typical arrangement where a separate receiver is not a part of the installation. Variable speed drive is necessary to "tune" take away rate to rate of product formation.*

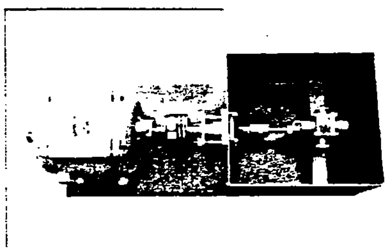


FIGURE 9. *Gearchem pump submerged horizontally in "bathtub" tank with direct motor drive.*

The submerged pumping system also allows close temperature control of pumped product by maintaining a desired bath temperature.

Pump Drives

Pump speed is an extremely important consideration in vacuum applications, since viscosities are often high, fluids are at or near their boiling points and flow rates may vary widely.

Undoubtedly, the most flexible drive system is one in which speed can be varied to meet changing process requirements. This is particularly true where a full-scale, separate receiver does not exist and the distillate pump takes suction from a "leg" at the bottom of a still of the type shown in Figure 10. Since distillate is often produced sporadically, a constant speed drive might empty the leg too quickly, allowing the pump to run dry and wear rapidly. Equipping the pump with a variable speed drive allows pump RPM and thus flow rate to be adjusted to the rate of distillate formation.

Another important reason for using variable speed drives is to accommodate changes in product viscosity. Where a vacuum still is to be used for a wide variety of applications, consideration should be given to furnishing all three pumps with variable speed drives. Each on so called "dedicated" stills, variable speed drive on distillate and bottoms pumps is a good idea to accommodate potential changes in operating temperatures, pressures and flow rates.

Variable speed drives may be either mechanical or electronic. Common styles in mechanical equip-

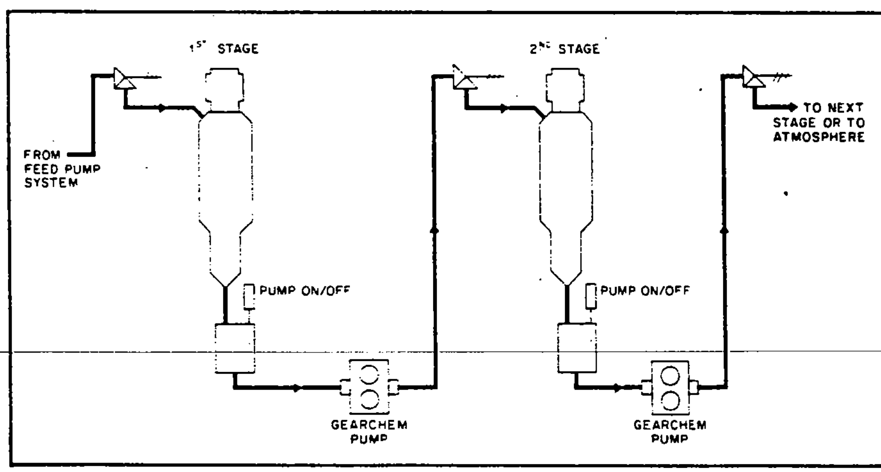


FIGURE 11. *Typical multi-pass system using multiple stills. Pumps are equipped with double mechanical seals.*

ment are units equipped with variable pitch pulleys and a special Vee-belt connecting them. For small horsepower requirements at slow speeds, variable stroke linkage drives are available that combine speed reduction (approximately 4.3 to 1) with speed variation. Electronic drives are most commonly DC motors with SCR controllers or AC motors with variable frequency controllers.

Feed pump rates can be controlled either by variable speed drives or by means of by-passing a variable portion of the pump output back to the supply tank. The former is shown in Figure 2 and the latter in Figure 1. Where feed stock viscosity is high, a variable speed drive is recommended.

Multi-Stage and Other Systems

In the production of many fine chemicals, a single pass through an evaporator does not produce product of the required quality. Gearchem pumps can be used to transfer or circulate from one vacuum system to another as shown in the simplified diagram, Figure 11. Another multiple pass system is shown in Figure 12, but in this case the same still is used with successively higher vacuums being drawn with each separation. The Gearchem pumps are equipped with double mechanical seals and liquid level controls on the receivers start and stop the pump drives as required.

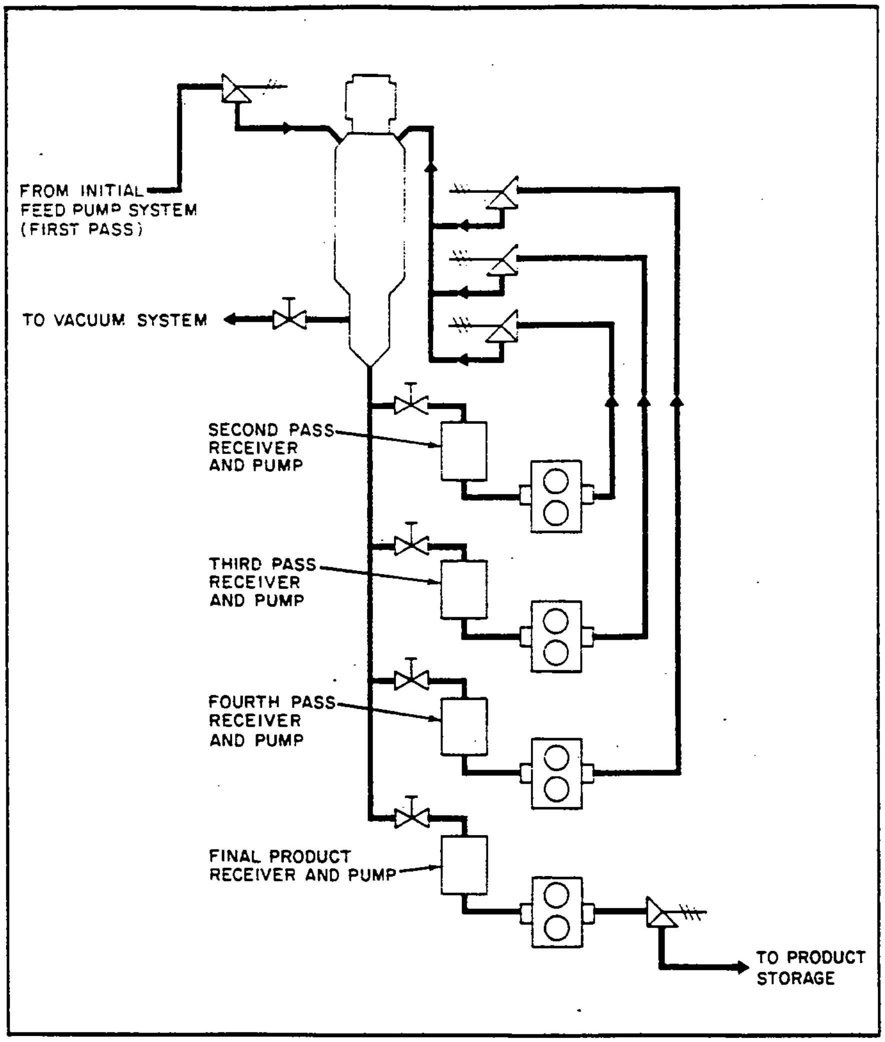


FIGURE 12. *Another multiple pass arrangement. Final product is highly refined.*

Summary

Liquid separations using heat have been in use since mankind first learned to increase the proof of his mead. The petroleum refining industry distills immense quantities of crude and semi-finished products hourly, and huge pumps are required.

In the production of fine chemicals using vacuum separation processes, small pumps in corrosion resisting alloys are essential since flow rates are usually quite small and the fluids handled are often very aggressive. In addition, the pumps must have shaft sealing arrangements that can maintain system vacuums that can be as high as 1 micron of Hg. absolute.

Eco Gearchem pumps handle flow rates from a few gallons per hour to over 20 gallons per minute, at differential pressures to 100 psig. They are available in types 316 and 304 stainless steels, Alloy 20, high-nickel Alloys B and C and in pure nickel. Drive and idler gears are furnished in a variety of metals and non-metallics, and carbon. TFE or phenolic bearings and wearplates, as well as ceramic for the latter, are available from stock.

Nearly twenty different shaft sealing arrangements are offered, although the most commonly used configurations in vacuum service are the double mechanical seal and the external seal for vacuum service.

In short, the Gearchem pump is designed by chemical engineers specifically for the process industries. The features described here are a result of many years of experience in all types of vacuum applications. They're intended to provide a superior pump which greatly simplifies the difficult problems of vacuum systems.