DEWATERING RADIOACTIVE RESINS & FILTER SLUDGE

A VACUUM COMPRESSION SYSTEM

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ABSTRACT

Dewatering radioactive bead resin slurries and filter sludge for disposal in liners and high integrity containers is rapidly increasing in the U.S. Techniques applied in the past have often required days to reliably reduce the water content of large containers to within regulatory limits. Results have been inconsistent and operating personnel have, on occasion, been subjected to unnecessary radiation exposure in their attempt to confirm performance. A technique has been developed that will reduce the process time of most filter sludges and bead resin to less than one work shift and, for many types of waste, to less than four hours. The process was developed by Stock Equipment Company, Chagrin Falls, Ohio and is being offered direct or as part of the services of LN Technologies, Columbia, South Carolina.

Tests have been performed on both nonradioactive and radioactive filter precoat materials and confirm the performance of the process and support equipment. Patents covering filters, filter arrangement, level instrumentation and process have been applied for. A Topical Report has been submitted to the Nuclear Regulatory Commission and the first dewatering operations at a nuclear utility have begun.

INTRODUCTION

The economic and regulatory environment of the 80s wrought sweeping changes in the handling and disposal of low-level radioactive waste. Regeneration of ion exchange media has become uneconomical at many plants and new stability criteria for solidified waste forms has the potential of eliminating some forms of solidification as viable procedures for waste processing. The net effect has been to increase the quantity of slurries processed to a dewatered condition and to increase the pressure on the technology required to support processing for disposal.

STOCK began to study the various techniques applied to slurry dewatering late in 1985 in response to numerous deficiencies reported in the industry literature. Bead resin that was not solidified was gravity drained using bottom filters coupled to a low capacity diaphragm pump. The technique is still used and requires several days of draining to achieve a high level of confidence that free water remaining in the resin bed will not continue to accumulate as to exceed the one-half percent regulatory limit.

Filter precoat and sludge dewatering has depended either on centrifugation or filtration. The former requires accurate control of slurry feed and, when working properly, will produce an excellent dewatered and consistent product. Horizontal drum type centrifuges, as opposed to bowl type, permit continuous operation and produce a cake with good density. But when the cake transfers to the shipping container, fracture occurs to such an extent that packing density is significantly reduced. Some users have experienced difficulty in maintaining a consistent, homogenous feed to the centrifuge with consequent and significant variation in cake moisture content and bypass of solids into the overflow.

Filtration is an obvious alternate technique for sludge dewatering. However, as it has been applied to dewatering low-level sludges, it is slow, subject to filter blinding, and marginal in producing cake with acceptable moisture content. The STOCK "Quick Dry" process was developed to address many of the problems that hamper conventional LLW slurry dewatering. The process is based both in theory and on two and one-half years of empirical small and large scale test work.

"Quick Dry", shown schematically in Fig. 1 uses the same basic skid mounted equipment to dewater both bead type ion exchange resin and filter sludge: a controlled slurry source, a filtrate

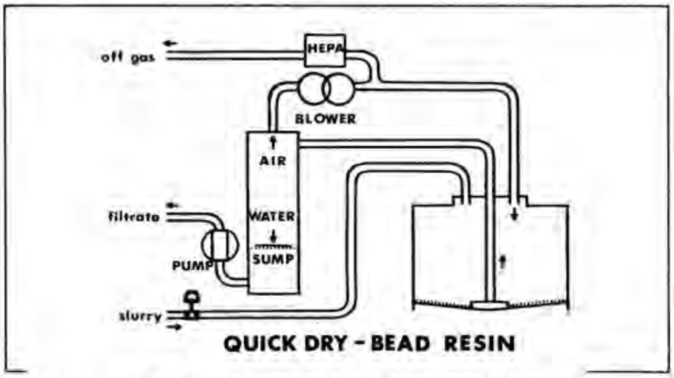

Fig. 1. Schematic of Skid and Liner.

pump a high capacity air blower, an air/water separator and an off-gas HEPA. With either waste type, slurry is transferred to the receiving vessel via a valved waste line under operator control. Since liners and HICs are closed vessels during processing, air displaced by slurry is vented from the vessel, bypasses the blower and passes out through a high efficiency filter to the facility off-gas system. Filtrate is withdrawn from the slurry by the negative pressure developed by a double-acting diaphragm pump and separated from air at the dewatering skid by a cyclone separator followed by a coalescing type demister. Filtrate enters a sump below the cyclone and is returned to radwaste holding tanks by the diaphragm pump.

When used in conjunction with bead resin dewatering, "Quick Dry" provides the force necessary to remove most of the water trapped by its own surface tension and viscosity at points of contact between beads. When applied to filter precoat slurries and sludges, "Quick Dry" characteristically reacts to the permeability of the waste media and transitions automatically from high volume, low pressure to a low volume, moderate pressure air flow which is necessary for filter sludge dewatering. The process is designed to take advantage of those characteristics of the waste slurry which facilitate the efficient dewatering of either granular or powdered media and applies the results of the research program at STOCK of the dewatering properties of these solids.

SLUDGE DEWATERING

Sludges are comprised primarily of finely divided solids originally used as filter precoats and foreign insoluable particulates that arise from water filtration and polishing operations. The precoat materials may include powdered ion exchange resin, fibrous organic media, diatomite, granular activated carbon and mixtures of the materials. When discharged from the precoat filters, the sludge is gravity settled and stored, often in a high solids state, until sufficient quantities have collected for disposal. Frequently, bead resins are collected in the same holding vessel, so the sludge may contain materials from several sources and of unknown concentrations. Particle size can range from a few to several thousand micrometers in cross section.

When the sludge is fifty percent or more filter precoat, it will form a moderately dense, compressible cake with up to eighty percent flooded interstitial space. The high percentage of void makes the media ideal for body filtration, hence its application as a filter precoat. These properties present unique problems to conventional dewatering processes, however, which must be understood in order to be controlled or circumvented to achieve efficiency and consistency in dewatering. They include: interstitial water rentention, cake permeability and diffusion.

Stress Cracking

As filtrate is removed from a slurry of precoat, an essentially homogeneous cake of loose, interlocking microscopic fibers forms, starting at the filters and moving outward and upward in the dewatering vessel. When the essentially supernatant water drops below the surface of the cake, the precoat fibers loose bouyant support and begin to settle in a more closely packed, but still reasonably plastic, random array. The net effect is a gradual shrinking of the cake as the free interstitial water retreats. As dewatering continues, air infiltrates the porous cake and the structure becomes far less plastic. So long as the entire cake is free to compress in on itself, the cake remains intact. However, filters distributed within the cake structure introduce discontinuities, and stresses develop in the cake along the filter surface. The cake immediately fractures and the cake to filter seal is breached. Tests have been conducted where cake was produced on flat, bottom filters in an attempt to avoid any discontinuities in the cake. But, as the cake receded from the sides of the dewatering vessel, it cracked, and air breached the cake along the bottom. Once air breaches the cake to filter seal, water removal nearly ceases, as it is now dependent on evaporation and diffusion of water to the air-dried surfaces. Some methods continue, assuming water removal by evaporation; others attempt to refill with slurry to regain the cake to filter seal. Neither approach addresses the problem directly and considerable time is required to achieve an acceptable free water end point.

Permeability and Compressibility

Permeability is a property of both filter media and the forming cake and refers to the ease by which a fluid passes through a porous media. Filter media for sludge dewatering must have porosity that is small enough to retain most of the fines in the slurry at the onset of filtration and yet pass filtrate freely. Many materials are available that are suitable for this purpose, but become clogged or blinded as filtrate carries small particles into the filter openings. In a similar way, the filter cake must have a high permeability, but permeability of filter cake is inversely proportional to cake thickness and typical radwaste cake can have section thickness in excess of six feet. Therefore, to maintain reasonable flow, many filters widely distributed within the dewatering vessel must be used. This is neither economical or volume efficient unless the filters are, in themselves, volume efficient.

Permeability will be affected by the compressibility of the cake and the pressure applied to move water held in the interstices. Since water will not move uniformly between all pores, channels of flow, or capillaries, are created in the cake along paths of least resistance, as in Fig. 2; the larger the channels and more numerous, the greater the flow to the filters. As pressure is applied, the cake is compressed and the channels narrow, reducing the flow. Under conditions of low pressure, however, forces that arise from fluid viscosity and surface tension also restrict flow. An optimum pressure, therefore, can be found for each cake type and filtrate that is a function of cake compressibility,

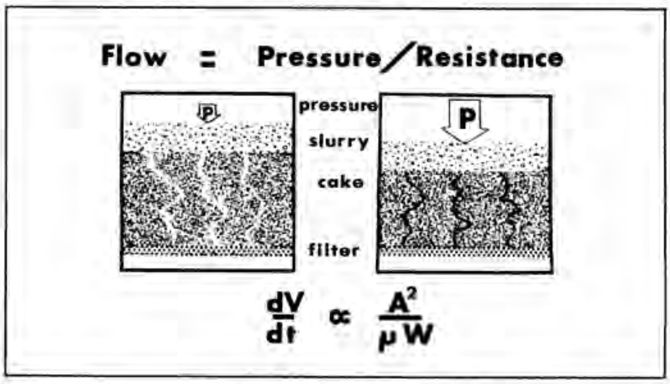

Fig. 2. Precoat Permeability.

particle size, particle mobility and filtrate temperature, viscosity and surface tension. The filtrate is easily characterized since in all cases it will be water. Temperature is the only controllable variable that will affect flow and flow will double with a 40 C rise. The cake, on the other hand, is far more variable and complex and samples should be obtained and tested to establish the optimum operating pressure.

Particle Size

Particle size participates in a significant way to rapid dewatering. A practical limit for filter media porosity is in the range of ten to fifteen micrometers. Below this range, water flow is dramatically reduced. However, sludge usually contains at least a small percentage of particles below this range. Some pass through the filter, some become lodged within the pores or body of the filter, but most will become distributed within the body of the cake and cause little interference with filtrate flow. High percentages of fines delivered in thin slurries and some gelatinous precipitates will blind any filter regardless of design. Coarse solids settle rapidly in thin slurries leaving most of the fines in suspension. This promotes their flow to the filter and/or the formation of an impermeable layer on the surface of the cake. Therefore, slurries must be delivered with as high a solids content as possible to increase the fraction of large particles in solution and, thereby, minimize the rate of flow of fines to the filter and promote the distribution of fines within the body of the cake. Efficient dewatering requires some knowledge of the permeability of the potential cake before the dewatering process commences.

Interstitial Water Retention

Materials suitable as filter precoats form necessarily homogeneous, porous cakes. Whereas this is ideal for body filtration, their natural water retention presents a formidable problem when determining an end point to dewatering. The Nuclear Regulatory Commission requires that class A waste contain no more than one-half percent free water as determined by the volume collected when the bottom of a burial container is punctured. Dewatering, therefore, cannot be completed until assurance is gained that after considerable storage and transportation, less than this limit will collect in the bottom of the burial container. There is no practical, routine method in use today that can provide this assurance because the hazardous nature of the waste usually precludes sampling and testing. And sampling, in itself, may not be representative due to the possibility of sampling along a dry fracture.

STOCK has studied this problem and tested many of the common materials, alone and in combination, as used by the utilities as filter precoats. A discussion of the material properties will aid in understanding the advantages provided by the "Quick Dry" process.

Filter aids, both ionic and nonionic forms, have been found to contain between 76 to 80 percent void space under comparable conditions of bulk density (0.8 gm/cc and 65 weight percent total moisture). During sludge dewatering, a 4.8 cubic meter vessel should contain at least 4.6 cubic meters of saturated cake at the moment when surface water just drops below the cake surface. As dewatering continues, water is removed from the interstices and the particles forming the loose cake reorient to a more compact but still saturated structure under their own weight, by forces that arise from the change in water content and by the differential pressure applied across the cake. Shrinking continues, evidenced at first by an annular space between the vessel wall and the receding cake, until the cake particles can no longer move closer together under their own weight. At that point the cake separates from the filters and dewatering stops.

Tests have recorded the average moisture content of precoat cake at 75 ± 1 weight percent when the seal from the cake to the filters is breached. Testing has also shown that when a cake contains as much as 72 weight percent moisture that free water will not drain unless the cake is acted on by an external force. But the cake particles can reorient so as to reduce the interstitial space when subjected to vibration. Diatomite is particularly sensitive to vibration and, as its interstices collapse, free water is displaced from the cake. In light of the handling and transportation that follows dewatering, it is apparent that steps must be taken in dewatering to assure the cake will not continue to compact enroute to the burial ground.

The "Quick Dry" process circumvents this problem and reestablishes filtrate flow by introduction of a compressive force across the cake that can exceed 83 kPa (12 psi). Compressibility of the cake permits expulsion of free water by the same force that acts to reduce the flooded void space within the cake. Water moves out of the cake in the same way water is expelled from a sponge when compressed. During the period that the cake is saturated and compressible it behaves as a hydrualic system where everything within the volume is subject to the same pressure, nominally 83 kPa. When the cake can no longer be compressed, pressure within the cake collapses to that of the applied pressure (14.3 kPa) and dissolved or trapped air within the cake expands. The expanding air and water vapor pushes capillary water toward the filters where it exits the system. Water discharged from in the cake is limited only by the extent to which the cake volume can be reduced and by the available capillary water. For common filter aid materials, water is consistently reduced to between 60 and 65 percent total moisture in one to two hours under compression. All filter aid cakes tested to date at 65 weight percent total moisture are friable and demonstrate no free water at nominal temperature and pressure. The cakes are not noticeably wet until the moisture content exceeds 72 weight percent.

From the preceeding discussion, it can be seen that if the volume of water expelled from the cake is recorded after the breach is first detected, then a measure of performance is available that permits total cake moisture to be estimated and referenced to a preferred end point. The "Quick Dry" system has this capability.

Continuing with the previous example, if a 4.6 cubic meter cake is 80 volume percent water at saturation, it can be determined that about 1200 liters of filtrate would have to be removed to achieve a moisture content of 65 weight percent (assuming a specific gravity of 1.40 for the cake solids). Of course, the true density of the precoat media must be known. The one used in the example is that of a popular ion exchange precoat that includes an organic fibrous material that improves its properties. The preceding estimate can be considered to be quite conservative because the precoat will include foreign insolubles that reduce its porosity and because the breach will occur about four percent below cake saturation.

It is prudent to note here that bulk material density cannot be used when making this or any other performance estimate of a dewatered cake as it is dependent on moisture content and the degrees of compaction.

THE "QUICK DRY" PROCESS

Dewatering of bead resins has been a routine process in the industry; dewatering filter precoat sludge has not. What is desired is an efficient process that enables an operating utility or service company to fill and dewater a liner of either material in less than one operating shift with an easily recognized process end point that assures burial site requirements are met. The STOCK "Quick Dry" process satisfies both of these requirements.

Vacuum Compression of Precoat

The vacuum compression process for filter precoat sludge dewatering overcomes the deficiencies of conventional dewatering techniques because it does not depend on air as the means for transport of free water. A unique liner equipped with 2.9 square meters of filter surface area per cubic meter of cake (0.9 sq. ft. per cu. ft.) and lined with a deformable plastic diaphragm is used to receive the waste slurry. Since no air is circulated, the liner has no vent connection to foul. Bulk water is removed during slurry transfer by application of a small positive pressure above the slurry and a negative pressure applied by conventional means via the filters. When the liner is completely filled with filter cake and most of the bulk water has been removed, the cake condition is similar to that obtained by conventional dewatering means. At this point, assuming cracks have not developed in the cake, air flow through the system is greatly restricted due to cake permeability, and does little to remove more water. Cracks, on the other hand, allow more air circulation but water removal is restricted to evaporation and diffusion.

Since the newly formed and nearly saturated cake is completely contained within a flexible, impermeable membrane, atmospheric pressure is applied across the cake by manually closing all entry ports to the membrane and maintaining a negative pressure on the filters. A compressive force in excess of 83 kPa is readily achieved across the cake. Since the initially saturated cake is compressible, the force is transmitted throughout the cake and free water is expelled via the distributed filter network. At constant pressure, flow from the cake is initially heavy, dropping exponentially with time, until most of the interstitial space has collapsed and capillary water has been exhausted.

Membrane

The vacuum compression membrane is a simple device that is fully supported by the liner during filling operations and by the cake during vacuum by compression. It is tear resistant and can easily support 400 percent of the operating pressure during filling operations. Punctures, should they develop during compression, do not affect the ability of the membrane to transfer force because it seals to the body of the cake. The membrane is reinforced by a nylon net which assures a bursting pressure in excess of the maximum permissible pressure of the liner.

Volume Efficiency

Despite the large filter area, volume efficiency is maintained by a filter design that occupies less than 42.5 liters (1.5 cu. ft.) of the liner volume. Liners have been consistently filled to better than ninety-five percent of available volume. Volume of the finished cake approaches fifty percent of the volume of the slurry settled for twenty-four hours.

Full Scale Tests

Eight full scale tests were conducted at STOCK over a three-month period. The test vessel was a production liner modified to permit removal of the upper head and shell. This permitted close and extensive examination of the filter cake. Simulated wastes used for testing the dewatering equipment were commercially available resins and filter media typically used by nuclear power plants. The simulated wastes were not contaminated, which enabled a considerable amount of data to be collected regarding the dewatered products.

After each dewatering procedure, the liner shell was lifted away from the freestanding cake. The cake was photographed and measured for height and girth before the membrane was removed. Immediately afterward the membrane was removed and 100 gram samples were taken from the side of the cake every six inches along a longitudinal line and approximately one inch below the surface of the cake. A similar set of samples were taken along the longitudinal centerline of the cake after the cake in front of the sample area was removed. Twenty-four samples per test were taken in this way for moisture determination. In addition, ten core samples were taken on each cake for bulk density measurements. The cores were taken in sets of three and 120 degrees apart, 15 cm. from the top and bottom and along the center perimeter of the side surface of the cake. An additional core was taken along the longitudinal centerline, near the bottom of the cake. All core densities were recorded and the moisture samples were analyzed on an Ohaus moisture balance that was operated to a maximum of 250 C so as to avoid scorching of the samples. In all, 235 samples were evaluated. Accuracy of the moisture measurement has been determined to be ± two percent.

Results of the moisture analysis of tests two through eight are shown graphically in Fig. 3. Test one was an equipment shake-down test and no moisture data was recorded. There are several important things to note from the figure: first, the repeatability of the data demonstrates the very forgiving nature of the "Quick Dry" process. Considering the initial inexperience of the test crew in handling the new equipment and maintaining a continuous flow of slurry to the test liner, and that several of the tests were interrupted and completed the following day, there is very little spread in the data. Second, tests six through eight reflect a significant change in procedure and dewatering efficiency and should be more representative of typical field operation. Finally, the axial moisture gradient is always present, regardless of the filtration process. Repositioning of the filters throughout the test series had no effect and cautions us against basing performance assumptions on data gathered from the upper portion of the cake.

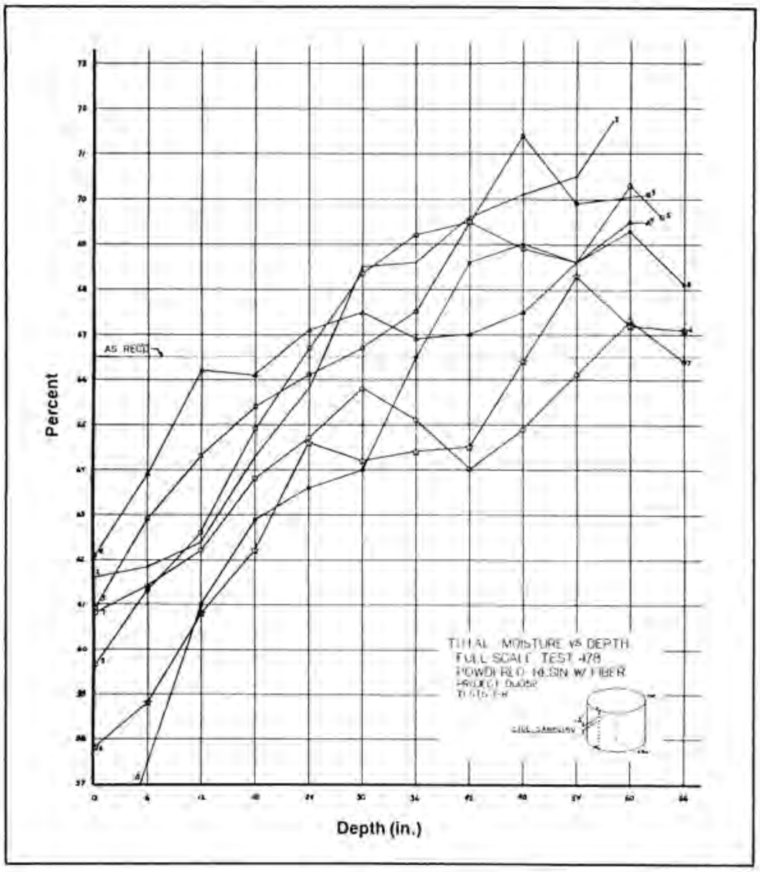

Fig. 3. Moisture, Surface Curves.

Figure 4 provides a comparison between the side and centerline moisture gradients of the last three tests. Considering the ± two percent accuracy of the moisture analysis, the data demonstrates little if any gradient.

Bulk Density, Equivalent Density and Performance

The significant increase in bulk density observed in each dewatering test, when compared to the "as received" density of precoat media, is misleading if it is viewed as a direct indication of the performance of any dewatering operation. Bulk density refers to total mass per unit volume and includes the void space and moisture content of the cake. The bulk density of most dry precoat materials falls far below 1 gm/cc and, for the same volume, will weigh more when moist. Volume reduction, on the other hand, should be viewed in terms of a decrease in the volume per unit of weight dry waste. The inverse of this, dry weight per unit volume, will be referred to hereafter as the equivalent density of the dewatered cake.

Table I provides a comparison of the same precoat under several dewatered conditions as illustrates how equivalent density reflects the true performance of a dewatering process.

TABLE I

Typical Filter Precoat
Bulk and Equivalent Density

Cake	Moisture w%	Bulk den. gm/cc	Equiv. den gm/cc
Settled	85.4	1.04	0.15
As received	66.5	0.577	0.19
Conv. filter	74.5	0.881	0.225
"Quick Dry"	65.0	0.801	0.28

Data from the last three tests in the test series are provided in Table II and represent expected field results on similar precoat materials.

TABLE II

Full Scale Test of Precoat
"Quick Dry" Equivalent Density

Test #	Samples N	Average Moisture Wt.%	Average Bulk den. gm/cc	Equiv. Density gm/cc
6	10	65.0	0.815	0.285
7	10	64.3	0.788	0.282
8	10	66.1	0.800	0.280
Sample average		64.7	0.800	0.282
Samle std. dev.		0.38	0.0014	0.0024

Tests conducted after the test series suggests that an equivalent density of up to 0.35 gm/cc is possible using this method.

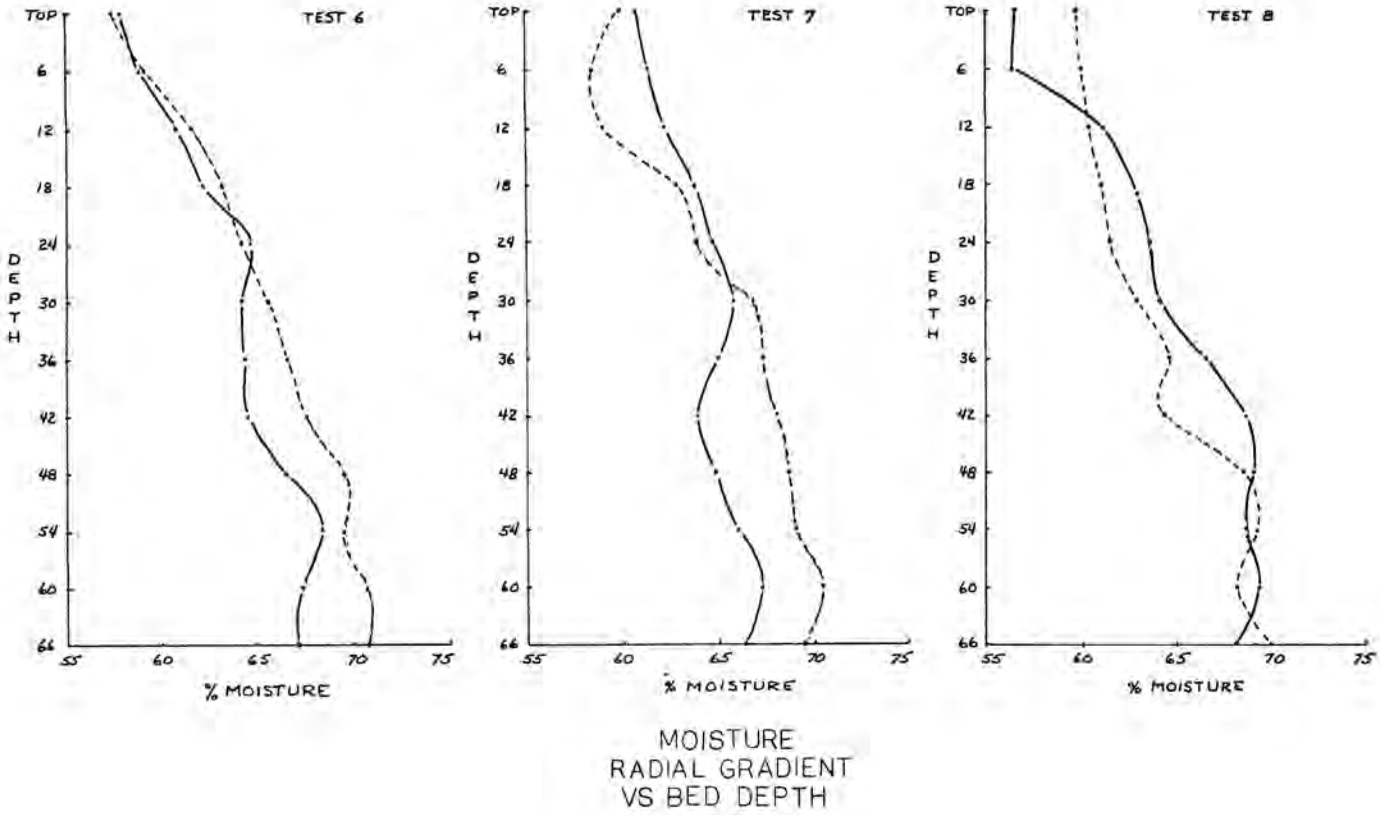

Fig. 4. Side/Center Gradient Test 6, 7, 8.

BEAD RESIN DEWATERING

The STOCK "Quick Dry" processing equipment can dewater either bead resin or filter precoat materials. The only requirement to change from precoat to bead resin dewatering is a change in the interconnecting hoses. The "Quick Dry" liner and method used with bead resin, however, differs considerably. For bead resin, a container with a conical bottom, preferably eight degrees above horizontal is used. This design, while keeping volume loss of the liner to a minimum, includes a disposable, full height, analog liquid level sensor and focuses drained water to a sump for easy removal. The entire bottom interior of the liner is fitted with a fine mesh screen and a porous screen support structure. Water draining through the resin by gravity and hydrostatic pressure is directed along the support member toward the sump. A vertical discharge pipe with a row of water collecting orifices secures the assembly to the bottom of the sump in the center of the liner. The granular property of bead resin permits rapid removal of the bulk interstitial water in the slurry. Hence, the liner sump is designed to maximize flow during initial dewatering. After this first phase, water flow diminishes rapidly to that of gravity draining of water trapped at points of contact between beads. Gravity draining requires several days for the flow to decrease to where less than one-half percent of the waste volume as water, continues to drain to the bottom of the liner.

With the "Quick Dry" processing equipment, an operator can complete this final phase of dewatering in approximately four hours by activating the same blower used for the vacuum compression of filter precoat cake. Three mechanisms are at work during this final phase of dewatering. First, the open structure of the bead resin bed permits flow of high velocity air heated by the blower. Air passing between adjacent beads provides turbulence that acts on water trapped at points of bead contact and moves the water along in the direction of air flow. Second, the heated air considerably reduces the viscosity of water trapped in the upper portion of the bed, which also aids in accelerating the dewatering process. Finally, water absorbed as vapor in the transport air is condensed further down in the cooler portion of the resin bed and is pushed along to the liner sump. Free water can be verified any time after processing by reconnecting the STOCK level instrument or by use of a dipstick inserted through the air/water discharge pipe located at the center of the liner manway.

Full Scale Bead Resin Tests

A total of eight full scale dewatering tests were performed as a final test series on bead resins. These tests confirmed previous test results. For the first seven, the remaining free water depth, measured a day after process completion, was from 5 to 10 centimeters in depth. In consideration of the conic angle of the liner bottom, this corresponds to 0.05

to 0.3% of liner volume. The last test was performed with the STOCK "Quick Dry" dewatering equipment. The equipment and procedure used in the last test will be used for dewatering bead resins in the field. Water that accumulated after the last test was 2.5 cm. of water, or 0.01% of the liner volume, after only four hours of blower operation. This level increased an additional 0.5 cm. after 10 days, still within 0.01%. Tests, where drying time was extended to five hours, showed no detectable water after one hour or 10 days of settling.

The STOCK "Quick Dry" process end point for bead resin at typically four hours of blower operation was determined by measuring the water removal rate and observing the condition of the dewatered product. When the water removal rate levels to a constant flow, typically at 75 cc per minute, free (drainable) water is no longer being removed. Instead, bead resin is being dehydrated in the upper portion of the resin bed and the vapor produced is condensing as the air moves to the lower, cooler portion of the bed. This constant, low flow rate will continue for some time and not reduce free water any further. After processing ends, the dehydrated resin will rehydrate, moving toward equilibrium with the rest of the resin, by decreasing the moisture lower down in the bed.

PREPARATION FOR FIELD USE

Early in 1985, STOCK began studying the market potential of the early results of the dewatering research program and gained the interest and support of a well-known nuclear waste service company, then NUS Process Service Corporation, later to become LN Technologies Corporation of Columbia, South Carolina. Through their efforts, sufficient filter aid and bead resin was obtained to permit both full scale dewatering test series. STOCK and LN developed the first prototype of the "Quick Dry" dewatering process skid. The first skid was used in all of the filter precoat full scale test work and the last full scale bead resin test performed at STOCK. The skid and a unique test liner were shipped to LN in mid-1986 to permit continued testing and extensive training of LN personnel. Since June of '86, LN has performed six additional filter precoat and six bead resin dewatering tests. In addition, several mixed media tests with 50% filter precoat and 50% bead resin have been performed. All tests at LN repeated the performance of test work at STOCK.

Fig. 5. Freestanding Precoat Cake.

Several new dewatering skids are being manufactured at STOCK's Lynn Haven, Florida plant that incorporate the field and hands-on operating experience of LN into the design. The new design will permit operation remote from the skid and, where necessary, out of the radwaste processing area. A third, small skid is also being manufactured that will handle all of the plant services and waste influent connections. Together the skids occupy less than three square meters (32 sq. ft.) of floor space.

Using nonradioactive media at STOCK and LN Technologies, the process has been demonstrated to several large nuclear utilities. The test liners ability to be lifted away from the dewatered cake permitted the freestanding cake to be inspected immediately after each filter precoat dewatering demonstration. The cake resulting from each demonstration was compact, freestanding, and dry in appearance, as in Fig. 5.

The original dewatering process equipment is presently at the Perry Nuclear Power Generating Station of the Cleveland Electric Illuminating Company in northern Ohio undergoing initial dewatering operations on low-level nuclear waste. A comprehensive, generic process control plan was customized for site operations in accordance with utility and NRC regulatory requirements. Core samples of the first dewatered filter precoat liner fell into the family of curves in **Fig. 1**. Testing is expected to continue at Perry through the first quarter of 1987.