PIPELINE TRANSPORT OF SHREDDED SOLID WASTE

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U.S. ENVIRONMENTAL PROTECTION AGENCY

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Final Report

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ABSTRACT

A brief summary is made of past and current studies on the pipeline transportation of solid waste. A plan is made for a proposed program to augment existing knowledge on this means of transport. The testing facility necessary to perform this plan is described and equipment layout sketches and material lists are provided. An economic analysis of a truck transfer system is presented and requirements for the economic analysis of a pipeline transport system are indicated.

This report was submitted in fulfillment of contract CPE-70-132 between the U.S. Department of Health, Education and Welfare, Bureau of Solid Waste Management and The Western Company.

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SECTION 1

CONCLUSIONS

The literature search revealed some prior work has been accomplished verifying that solid waste can be transported in a slurry form through pipelines just as many other materials have been over the past 30 years. There are accessory operations which are required by a slurry transport system which have not been perfected for a solid waste system. The grinding of solid waste, while possible, is not as efficient or predictable as desired. The state-of-the-art of introducing the wastes into the pipeline has not been perfected. Dewatering units have been used for many materials but never for solid waste slurries. Although solid waste research programs are now in progress using some methods of slurry dewatering, the results are as yet unpublished. Finally, while all of the unit operations associated with slurry transport have been used on other products, they have yet to be all put together in a single solid waste slurry transport system. The program plan outlined in this study will put it all together.

Capsule transport to date has been done only on a laboratory scale. Evaluation of the laboratory scale capsule transport shows some potential benefits over slurry transport.

To be economically feasible, any pipe transport system must compete with the current method of transport to the disposal site. Pipelines represent an alternative transport mechanism which can be most readily integrated into a transfer station operation. Typical cost of a transfer station with large compacter truck haul to the disposal site is $.09 per ton mile of trash handled on a round trip mileage basis.

RECOMMENDATIONS

To increase the available information on solid waste handling, it is recommended that the program plan outlined in this study be undertaken at the earliest opportunity. It is further recommended that the unit operations necessary for the slurry transport be used in their present state of development, rather than attempt to optimize their operation during this study. If the results of this program show economic or other tangible benefits, work should be undertaken to optimize the various unit operations used in the pipe transport of solid waste and a complete transport system demonstrated on the municipal level.

SECTION 2

INTRODUCTION

The solid waste problem has been characterized as a health pr·blem which needs an engineering solution.[1] It has been estimated that 75 percent of the cost of disposing of solid waste is in the collection and transportation to a disposal site. Some $ 3 billion are spent annually in the United States to collect and dispose of solid refuse. The collection and disposal practices in common usage are but little improved over those of a quarter century ago.[2]

The trend toward concentration of people plus the increase in poundage of refuse per person is compounding the problem. The cost and the air pollution problems which are currently inherent with incineration has resulted in most cities turning to the only acceptable alternative technique--sanitary landfill. However, in many areas there are no satisfactory landfill sites within a reasonable distance. The long haul distances plus the hazards and restrictions imposed upon refuse trucks moving through suburban cities creates a major problem, particularly for large metropolitan areas.

An engineering solution for one facet of the solid waste collection and disposal would be the use of a pipeline to transport solid wastes the long distances from collection area to disposal site. Traditionally, pipelining has many advantages over truck transport, such as reduced transportation costs, less recurring capital costs, less labor costs, etc.

Background

Presently, there are no programs ongoing which study the complete pressure system of pipe transport of solid wastes in other than a theoretical manner. The Foster-Miller Associates household grinder contract (CPE-70-115) is, in essence, experimentally studying a complete pipe transport system in connection with nonpressure flow in sewer pipelines. There are projects completed or in progress which are examining unit operations required by a pipe transport system. For example, size reduction of solid waste has been done at Madison, Wisconsin, for direct landfill. Size reduction has been done at Gainesville, Florida, for composting solid waste and also at New York City and other towns to aid in incineration of the waste.

Zandi, at the University of Pennsylvania, has studied the hydrodynamics of various concentrations of solid waste slurries and has pumped solid waste slurries through three size of pilot pipelines.[3] Stanford Research Institute is doing an examination of hydraulic pipe transport of solid waste in slurry, capsules, and slugs.[4] To date all of their work has been entirely theoretical with pilot pipelines to be constructed later. No other programs which dealt with the actual hydraulic transport of solid waste was found.

Slurry Transport

Slurry transport of solid material through pipes is a handling process used many years by various industries. The flow of slurries in pipes, however, cannot be qualified by density and viscosity as can pure fluids. Because of the interaction between fluid and solid and the properties of the solid and fluid, each system must be treated individually. The solids-carrying pipelines now in use have been designed and modified by the use of empirical formulas and large-scale tests using the specific solid being transported. For example, Condolios, through such testing, limits the particle size to no more than one-half the transport pipe diameter.[5]

A recent program has been completed in which development of empirical data was made on the slurry transport of ground solid wastes. Zandi and Hayden have demonstrated that solid wastes, sufficiently ground and pulped can be transported through a pipe.[6] Formulas were developed which will allow calculation of pressure losses from a knowledge of pipe diameter, mean velocity, and solids concentration. It was further demonstrated that a solid waste slurry behaves, from a pressure loss standpoint, identically with a slurry formed from only the paper portion of the solid waste.

Hayden observed pressure losses of approximately 500 psi per mile when transporting a 10 percent solid waste slurry at 3.7 feet per second through a 6-inch pipe.

Capsule Transport

Hydraulic capsule transport of solids can be used when the solid cannot stand contamination from the carrier fluid or when the separation of the solid from the carrier is difficult or expensive. Experimental work to date on capsule transport has been on a laboratory scale only.

Ellis investigated both single spherical and single cylindrical capsule transport in a 1 1/4-inch diameter pipe.[7] He found that the velocity of the capsule varied from 1.05 to 1.5 times the average water velocity which ranged from 0.20 to 12.15 feet per second. The velocity ratio increases with increasing length/diameter ratio of the capsules. Trebling the L/d ratio increased the velocity ratio about 3 percent. The presence of the capsule appeared to delay the onset of turbulence in the annulus between the capsule and the wall to a much higher value of Reynolds number than would hold in unobstructed fluid flow. This indicates a reduction in normal head losses as a result of the capsule being transported.

Evaluation of the small scale tests indicated favorable possibilities in the use of hydraulic capsule transports assuming scale up to commercial quantities is possible. Among the benefits indicated are:

- lower power requirements
- minimum expense in separating the capsule from the carrier fluid.

Information on the technical feasibility or cost of forming the capsules from solid waste was not found in the literature.

Size Reduction

The size reduction of solid waste presents an unusual problem. The unlimited variety in the composition of solid waste with regard to density, size, shape, and composition of the components increases the difficulty in selecting and sizing the necessary equipment.

Size reduction is a grinding and crushing operation. Crushing denotes size reduction by the application of compression stresses which in turn cause tensile and shear stresses to break the particle. Grinding is size reduction due to abrasive or attrition forces.

The common hammermill combines both these forces in its operation. Sanders reports satisfactory size reduction and homogenizing of solid waste when passed through a hammermill.[8] He indicates a grate size (1.5-inch) but does not state the resulting particle size or range of particle sizes.

Wixson reports the reduction of urban solid wastes is generally feasible by use of the hammermill.[9] Here again the grate size is given (3/4-inch) but no resultant particle size range.

Zandi and Hayden report that the hammermill is capable of presizing solid wastes but requires considerable maintenance.[6] They further stated that, while sufficient size reduction for pipe transport is possible, a more efficient system must be developed for an actual industrial application. However, in their solid waste transport study, a two-stage reduction, a combination of a Wascon pulper and a Dorr-Oliver Gorator, was used.

The city of Madison, Wisconsin, started a solid waste reduction study using a horizontal mill (a Gondard) but ended the study using a vertical mill made by Tollemache.[10] This study related to direct landfill and did not report the particle size range resulting from the reduction.

Solid Waste Composition

The physical and chemical characteristics of the waste material, as determined by its composition, has a significant impact on the handling of solid wastes. The as-collected household and commercial refuse is composed of varying amounts of each general group of the various waste categories. Table 1 indicates the primary components of each refuse group.

The actual percentage of any caregory from a specific location on any given day is dependent on the geographic location, season of the year, day of the week, the economic status of the collection area, and many other variables.

Niessen and Chansky in their study have defined the nature of solid waste and projected the quantity and composition through the year 2000.[11] They predict an increase in the total solid waste load by a factor of 2.7 by the year 2000 with the ratio of paper and plastics increasing and food wastes and yard wastes decreasing. Table 2 lists the solid waste composition range in a number of U.S. cities.

From the wide range in composition of the various categories, the difficulty in obtaining a uniform solid waste from an as-collected municipal source can be easily understood. Therefore, a synthetic or manufactured solid waste will be required, for uniform or equivalent products during pipe transport tests. The manufactured solid waste composition could be expected to conform to the average shown in Table 2.

Limitations

To date, no previous work has been found which demonstrates equipment or methods to introduce presized solid waste particles into a slurry transport line on a regular and continuous basis. Nothing is reported yet on the largest solid waste particle size which can be made into a pumpable slurry. Zandi and Hayden reduced the solid waste to a pulp, evidently uniformly approaching the size of the paper fibers. No method has been demonstrated which will introduce the presized solid waste into a pipeline running full.

Wixson's study pumped the solid waste slurry from a main reservoir and returned the slurry to the same reservoir for further cycling. Zandi and Hayden also recirculated the slurry from a mixing tank.

The slurry transport pipe system has also been neglected at the discharge end. The dewatering method or degree of dewatering has not been demonstrated, nor has the disposition of the carrier fluid been specified. The handling of the dewatered slurry should be possible in conventional equipment. Metcalf and Eddy, under subcontract to the Environmental Protection Agency Contract with Foster-Miller Associates have performed bench-scale studies of the vacuum filtration of solid waste slurries. Indications are that this method is quite successful. Screw press dewatering of pulped refuse is also being practiced in New Haven, Connecticut, as a part of EPA Contract PH-86-67-167 ''Solid Waste Research in the Application of On Site Refuse Storage, Colle·tion and Reduction Systems for High-Rise Residential Structures... The results of these efforts have not yet been published.

Polymer Use

Current oil field technology uses polymers as additives to water to improve the solid carrying capacity and as a friction reducer. The oil field use requires the suspending of sand, glass beads, aluminum shot, ground walnut shells, and other materials in very high concentration. This suspended material must be moved in large volume through small pipe requiring high pump horsepower. The polymers used, in addition to their suspension qualities, reduce the boundary layer turbulence thereby lowering the friction loss in moving through the pipe. It is believed that similar polymers may act as a suspension aid and a friction reducer in the slurry transport of solid waste. The polymers for this application can be found in the general class of polyelectrolytes used in water and sewage treatment and paper manufacturing as coagulants or coagulant aids. Appendix A lists manufacturers and products which have been used or considered as friction reducing materials and suspension aids.

The following criteria should be used in determining the best polymer additive for use in the waste slurry transport.

- friction reduction capability
- Solubility in water
- high molecular weight
- shear stability in flow systems

- storage life
- toxicity to biological systems
- resistance to biological attack
- chemical stability under repeated use
- availability from commercial sources
- cost.

Purpose

The purpose of this program is to advance the knowledge and technology toward better methods of solid waste management. The total program will result in the generation and collection of data to show to what extent pipelining of solid waste is a practical and economic process. The program will also result in design data necessary to construct a demonstration project in the slurry pipelining of solid waste.

Scope

The scope of this phase of the program is limited to the investigation and evaluation of the state-of-the-art of slurry transport of solid waste and the development of a test plan to acquire the data necessary to design and demonstrate a complete operational pipeline slurry transport system for solid waste. The system under investigation is to involve the transport of solid waste from the collection area to the point of disposal.

Program Description and Approach

To meet the purpose and scope of the program, the work was divided into four areas. The first area of investigation was the review of all work completed and ongoing studies. This was done to take advantage of the available information, to learn of needed areas of investigation, and to prevent duplication of effort. The second work area was a detailed plan on the number, kind, and variation of tests which would be conducted. The test plan took into account the variables which would exist in each test, for example, amount of polymer, solids concentration, flow velocity, size of solids, data to be taken, etc. The third area of work consisted of the designing of a pilot system which could provide a maximum of needed data with a minimum of equipment cost for the several types of tests to be performed. Economy and ease of operation were considered second only to the capability of providing acceptable data. The last work area was an economic analysis of a typical refuse truck transfer transportation system for comparison later to the transportation costs developed for a typical pipeline transportation system.

TABLE 1

REFUSE DESCRIPTION

Category	Description
Glass	Bottles (primarily)
Metal	Cans, wires, and foil
Paper	Various types, some with fillers
Plastics	Polyvinyl Chloride, Polyethylene, Styrene, etc., as found in packaging, housewares, furniture, toys, and nonwoven synthetics
Leather, Rubber	Shoes, tires, toys, etc.
Textiles	Cellulosic, protein, woven synthetics
Wood	Wooden packaging, furniture, logs, twigs
Food Wastes	Garbage
Miscellaneous	Inorganic ash, stones, dust
Yard Wastes	Grass, brush, shrub trimmings

TABLE 2

RANGE IN COMPOSITION OF RESIDENTIAL
SOLID WASTES IN 21 U.S. CITIES*

Category	Percent Composition by Ne . Weight		
	Low	High	Average
Glass and Ceramics	3.7	23.2	9.0
Metals	6.6	14.5	9.1
Paper Products	13.0	62.0	43.8
Plastics, Rubber, and Leather	1.6	5.8	3.0
Textiles	1.4	7.8	2.7
Wood	0.4	7.5	2.5
Food Waste	0.8	36.0	18.2
Rock Dirt, Ash, etc.	0.2	12.5	3.7
Garden Waste	0.3	33.3	7.9

* Unpublished data, Division of Technical Operation, Bureau of Solid Waste Management. Values were determined from data taken at 21 cities in continental United States between 1966 and 1969.

SECTION 3

DISCUSSION AND TECHNICAL CONSIDERATIONS

Technical Approach

Test Plan Logic

Before any flow tests can be made, certain basic data must be collected, and operating procedures established. Results, in terms of particle size ranges must be obtained from the various screen plate openings on the size reduction units. Injection techniques must be developed which will result in a uniform slurry in the pipe and a consistent injection of capsules. The test facility must then be calibrated by transporting a solid waste slurry, measuring the results, and comparing the results to previous work by others.

Figure 1, from Zandi and Hayden, shows the pressure losses observed as a result of solid waste concentration and velocity changes. It appears from the graph that pressure losses of all solid waste slurries of seven percent concentration and above are independent of the velocity. However, examination of the curve for the six percent slurry shows its pressure losses to be velocity dependent for the low velocities of two to five feet per second. At velocities above six feet per second, the pressure losses are approximately parallel to the pressure loss line for water. The referenced paper did not report any velocities greater than shown on the graph because the upper limit of pump capacity had been reached. If it can be assumed that the slurries higher than six percent concentration will behave similarly to the six percent slurry it will only be necessary to increase the velocity of each concentration until the curve breaks upward.

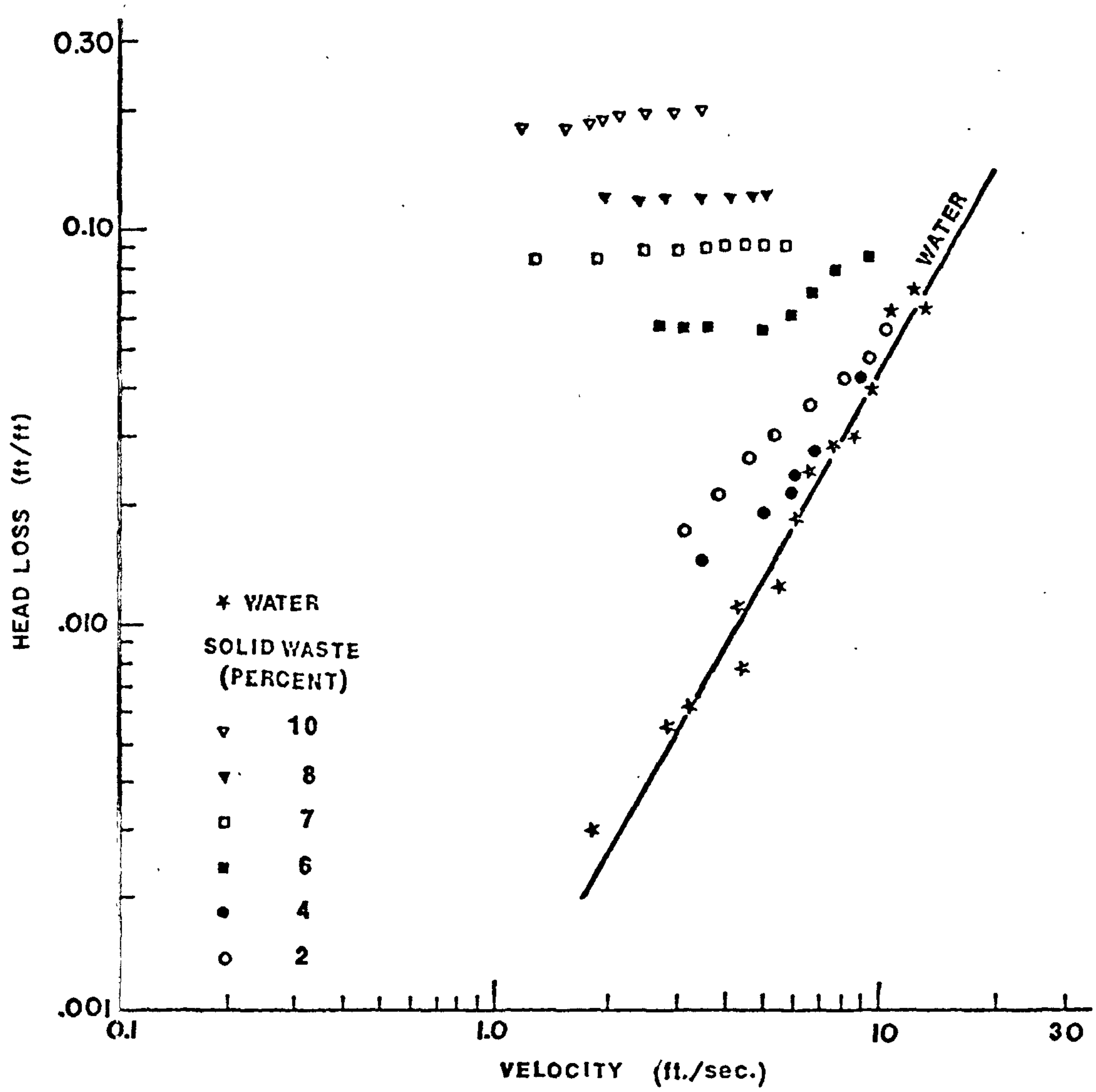

Figure 1. Concentration Effect, 6 inch Pipe from Zandi, I and J. Hayden. (Reference 6).

Capability and capacity tests must be run on the dewatering device, not for the purpose of optimizing the dewatering, but to define quantitatively what dewatering results are being accomplished. The accumulation of such basic data will provide insights into the transport tests and permit the most efficient performance of those tests.

The capsules for this test will be made of polyethylene bags, 5 inches in diameter, filled with ground solid waste, compacted to the fill density listed in the test program, and heat sealed. The capsule length/diameter ratio should not exceed 3/1 due to the dimensions of the available rotary valve used for insertion.

The transport tests, both slurry and capsule, will result in the establishment of transport rates, power requirements and losses. Once the optimum transport conditions have been established, fluid reuse tests will be made, which should show savings possible through reuse of the carrier fluid. Again, in establishing optimum conditions, the slurry solids concentration will be increased to find the highest concentration which can be transported. Optimum conditions in this instance means the highest transport rate with the least power requirement and losses.

Test Program Requirements

The test program is outlined in Appendix B. The methods and sequence of performing the tests are discussed. A detailed test plan gives specifics on the test variables to be examined.

Sizing

The first information needed prior to the injection tests is a particle size range resulting from the use of various size screen plates or grate bars in the grinders. It is not intended to optimize the grinding or grinders. Here again, knowledge is needed to define the operating conditions during the transport tests.

Three tests will be performed with each grate size; 1-inch, 2-inch, and 3-inch openings. The output will be classified on Tyler Standard screens, 2 to 1 opening ratio, 14 mesh to 3-inch opening, (7 screens). The results will be reported by percentage passing through each screen. A solid waste particle size classifier is being developed in-house by the EPA in Cincinnati. It is a potential candidate for performing this aspect of the testing.

Injection

Two general methods to inject solids into a pipeline are: pump installations using sludge or solids handling pumps, and pump installation using clear water pumps. To determine the best injection technique, both methods will be used. The criteria for the best injection system will be that system which can produce a uniform slurry concentration using the least amount of work added to the system. The measurements required will be: work required to inject solids (kilowatthours, foot-pounds, horsepower, etc.), the resulting slurry concentration, and the rate of slurry generation in gallons per minute, pounds per minute, etc.

The solids handling pump will take suction from the bottom of a reservoir into which a measured rate of water and ground solid waste is being inserted. Three tests each using different particle distributions and nine solids insertion rates will be performed.

The clear water pump will take suction from a reservoir with the solids introduced into the pump discharge through an eductor. In each type solid introduction, three tests each will be made using three different maximum particle sizes and six solids insertion rates.

It will be necessary to determine the head losses obtained transporting slurry in the test facility being constructed for this program. These head losses when compared with previous work done by others, will provide a baseline for calculating improvements or efficiencies resulting from this new work. The head loss determination will be accomplished while holding the solid concentration constant at 4, 6, and 8 percent, using one injection technique, the best grinder grate size, and flow velocities from 2 to 12 feet per second. Measurements during the test will include screen analysis of solid waste, input of water and solid waste, flow rate of slurry, and resulting pressure and pressure losses.

Dewatering

The capacity of the dewatering equipment will be measured by varying the slurry feed to the unit and measuring the slurry concentration, quantity of water removed, and water content of the dewatered slurry. If there is a vacuum capability on the dewatering unit, it will be varied and appropriate measurements made.

Transport Testing

The following parameters need to be considered when performing the slurry transport tests: velocity, particle size, slurry concentration, polymer used, and polymer concentration. The test range of each of these variables should be:

Velocity - 1.0 to 14 feet per second

Maximum particle size - dependent on information in baseline tests

Slurry concentration - 2 to 10 percent

Polymer - Polyacrylamide or acrylate/acrylamide copolymer

Polymer concentration - 10 to 100 ppm

The flow velocity will be measured. The particle sizes will be determined by screen analysis. The slurry concentration will be determined by measuring water and solid waste input and confirmed by analysis. The polymer concentration will be calculated from application rates. The pressure losses will be measured.

The test items to be considered during capsule transport without polymer are: capsule weight and shape, fluid velocity and capsule insertion rate. Tests to be run are:

1. Three capsule configurations
2. Fluid velocities
3. Three capsule fill densities
4. Three capsule spacings

Measurements will be made of head loss and capsule velocity. Transport rates will be calculated and capsule damage will be noted.

The following test items are to be considered during the gravity slurry transport tests. These tests are to be conducted with the pipe running half full?

- Velocity 1 to 4 ft/sec
- Solids concentration 1 to 9 percent

Measurements will be made of the fluid velocity, transport rates, and slope required to obtain the required velocity. Visual observations will be made of saltation tendencies of the slurry.

The gravity slurry transport with polymer will consider the same items, and make the same measurements with the following additions?

- Two polymers will be used
- Three polymer concentrations will be used

Carrier fluid reuse tests will be conducted for:

1. Slurry - the fluid will be recovered and recycled a minimum of 10 times. Polymer degradation will be measured on a viscometer and bacterial accumulation will be determined by a plate count after each cycle.

2. Capsule - the fluid will be recovered and recycled a minimum of 10 times. Measurement of polymer degradation and bacterial accumulation will be determined as in the slurry fluid reuse tests.

In determining the most efficient flow velocity, particle size, polymer, and polymer concentration, tests will be run with increasing slurry solids concentration measuring the flow rate and head loss. Figure 2 is a flow chart of the test plan.

Facilities Requirements

The test facility drawings and equipment list are presented in Appendix C. Schematic layout drawings are presented of the three major tests. An Isometric of the general equipment layout is included.

The pilot transport facility was designed for maximum flexibility in test setups. The grinder, storage tanks, pump, test pipe section and dewatering device will all be permanently located with test changes made by changing elevator location, removing a spool from the pipeline for rotary valve or eductor insertion, etc.

The grinder, a hammermill, will be equipped with a suitable hopper and three grates with 1- to 3-inch openings. The elevators can be screw, bucket or pneumatic of the capacity noted on the equipment list. The storage tanks should be mild steel, painted or galvanized corrugated iron construction. The ground waste storage bin must not necessarily be shaped exactly as shown on the isometric general layout drawing (figure C-4). The ground refuse by its nature is very reluctant to flow and is highly susceptible to bridging in a holding tank. In general, constrictions in movement must be avoided with this material. The slurry mix tank will require motor driven agitation to achieve complete mixing. The legs should support the tanks high enough to allow working under the cone, if necessary, to change piping or other hookups. The pump will be capable of handling solids up to three inches in diameter and variable in pumping rate by changing the motor speed. A gasoline driven trash handling centrifugal pump will probably be best suited for this temporary application. The magnetic flow meter is used because of no internal obstructions. The test pipe section requires six inch cast iron or epoxy lined steel pipe. When the solids are being inserted in the pressure side of the pump via the eductor, the solids from the ground storage tank will be discharged directly from the metering feeder into the eductor hopper. When capsules are being inserted in the pressure side of the pump, a slat conveyor will move the capsules to the rotary valve. The Geneva drives of the conveyor and rotary valve will be synchronized so that the conveyor will drop a capsule during the valve rest cycle. The pressure measurements will be made by pressure transducers located at the pressure tap locations noted on the schematic drawings. The pressure will be transmitted through an oil filled chamber from the flush mounted diaphragm to the transducer. The pressure differential will be determined electronically and displayed on a direct readout recorder.

The dewatering unit will have the capacity indicated on the equipment list and will be a revolving or vibrating screen with or without vacuum assistance, a dewatering screw and press or some other suitable type of water removal process. There will be a capability of returning the removed water to the slurry tank for subsequent carrier reuse tests.

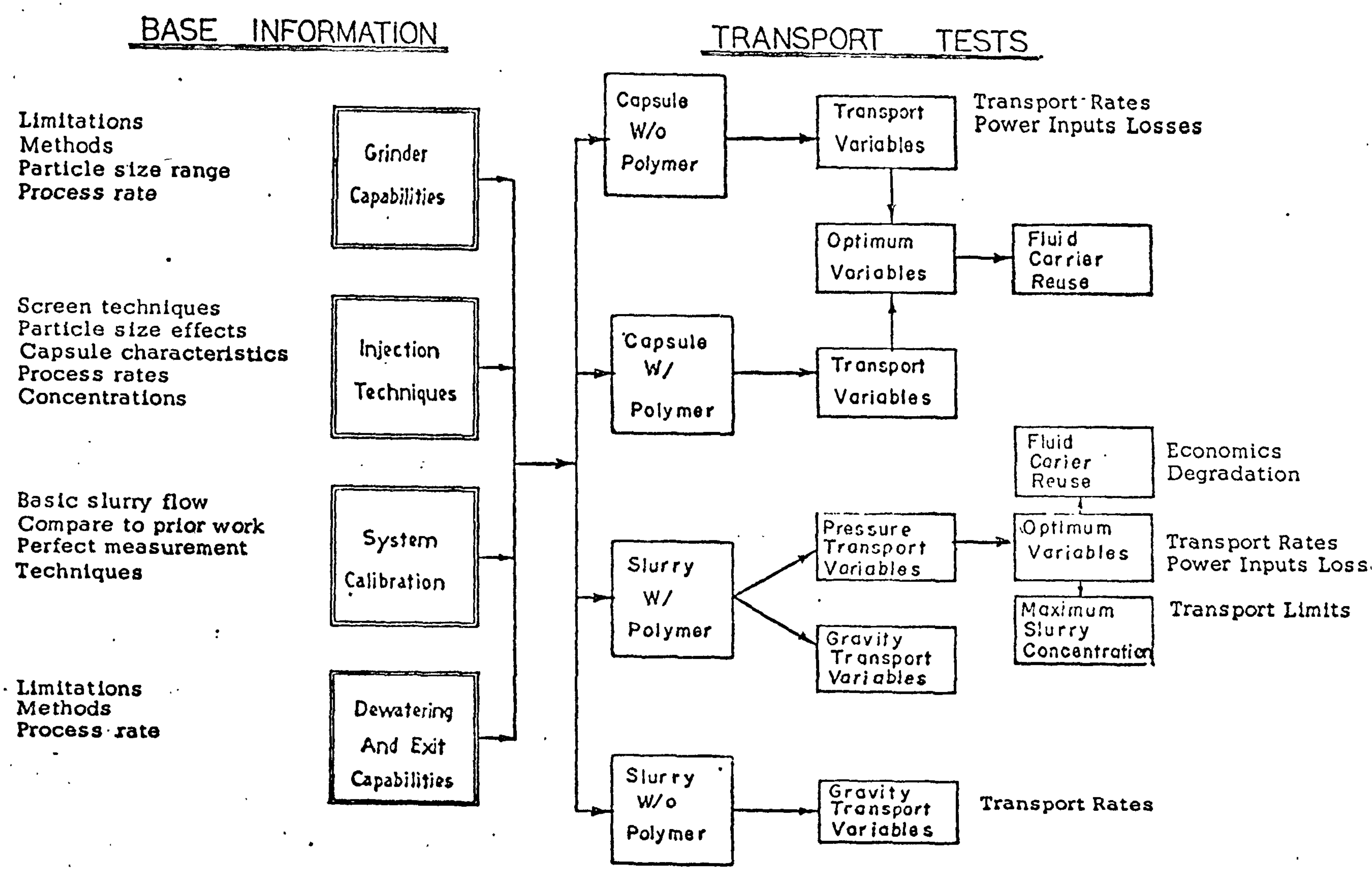

Figure 2. Test Plan Format

Economic Considerations

Any evaluation effort dealing with an operational problem, such as solid waste management, lacks meaning and relevance without the parallel development of a standard of comparison. In addition, past and current programs have not, for the most part, evaluated pipeline systems that are truly representative models of anticipated operating conditions. The technical evaluation cannot be divorced from economic evaluation of the system, including a comparison with other available alternatives.

The proposed program will result in data identifying the operating characteristics of a pipeline system model that will be representative of anticipated full-scale operating conditions and practice. This basic data can be used to provide a realistic evaluation of a pipeline system compared to other transport alternatives, and as a standard of comparison for the evaluation of potential improvements to pipeline operations such as polymer and capsules. As a result, the data will permit a realistic appraisal of both investment cost and recurring operating cost for both the basic pipeline concept and the specific potential improvements to be investigated.

The program proposed is primarily addressed to the utilization of pipelines as an alternative in the solid waste transfer station operation. Due to the large geographic variation in operating conditions and results it is felt to be most productive to analyze carefully a specific application. From the standpoint of comparability and ease of potential early implementation, the transfer operation is well suited to the pipeline application. Within that operation, the long haul truck transport mechanism is the current practice and the appropriate standard of comparison for a pipeline.

Figure 3 portrays a comparison of the two alternative systems in terms of their functional components. To be valid, the economic evaluation must compare equivalent systems and these components identify the basis of such a comparison. It is assumed that the equivalent systems identified in the figure have no influence on the operating characteristics of units outside either system. With this assumption, for example, collection schedules and resulting input to the systems are fixed. Investment (and resulting operating costs) for this fixed handling capability is the variable of comparison between these systems.

Appendix D outlines the operating characteristics and economics of an operational and typical truck transfer system. It is intended that a pipeline system operation, based on the results of the proposed testing, will be compared to the key performance measures developed in the Appendix.

Specifically, the Appendix indicates that the pipeline must process a given quantity at less than $2.83 per ton or about $.09 per ton mile for a 33 mile round trip to justify as an alternative to truck transport. These operating costs are also shown to be within the ranges established through previous analysis.[12, 13, 14, 15] It is also useful to more directly identify these costs with functional components such as station operations and transport operations. In this way, a clearer picture of the less competitive aspects and sensitivities of each system can be given.

The equivalent systems identified in Figure 3 relate only to the direct costs associated with each system. Overhead costs are not considered. It is assumed that these are fixed relative to any transport alternative and need not be included. Some differences other than direct cost must also be taken into account, however. Most important of these are the differences in the impact of each system on the environment. Noise, odor, litter, traffic congestion, and other nuisance costs associated with truck transport which are reduced or eliminated with a pipeline must be taken into account. Many of these are effectively intangibles. However, methods for approximating their value have been attempted and should be utilized.[16]

While the operating measures of cost per ton and cost per ton mile are useful and common tools in the economic comparison of alternatives, they fail to take into account a fundamental difference in the nature of the alternatives.

Pipeline transport represents a high initial investment relative to truck transport in anticipation of lower operating costs. The truck system represents smaller incremental, but more frequent investment requirements. Operating measures such as cost per ton do not take funds flow or the timing of cash outlays into account. To recognize these differences, the system must be ultimately compared on the basis of the discounted or present value of the cash flows they require. The discount rate employed in this analysis should represent the cost of capital to the cognizant operating unit. It is anticipated that a rate of about 8-10 percent would be appropriate. However, the analysis should be conducted over a range large enough to reflect changing financial conditions and identify the limits of economic justification of each system.

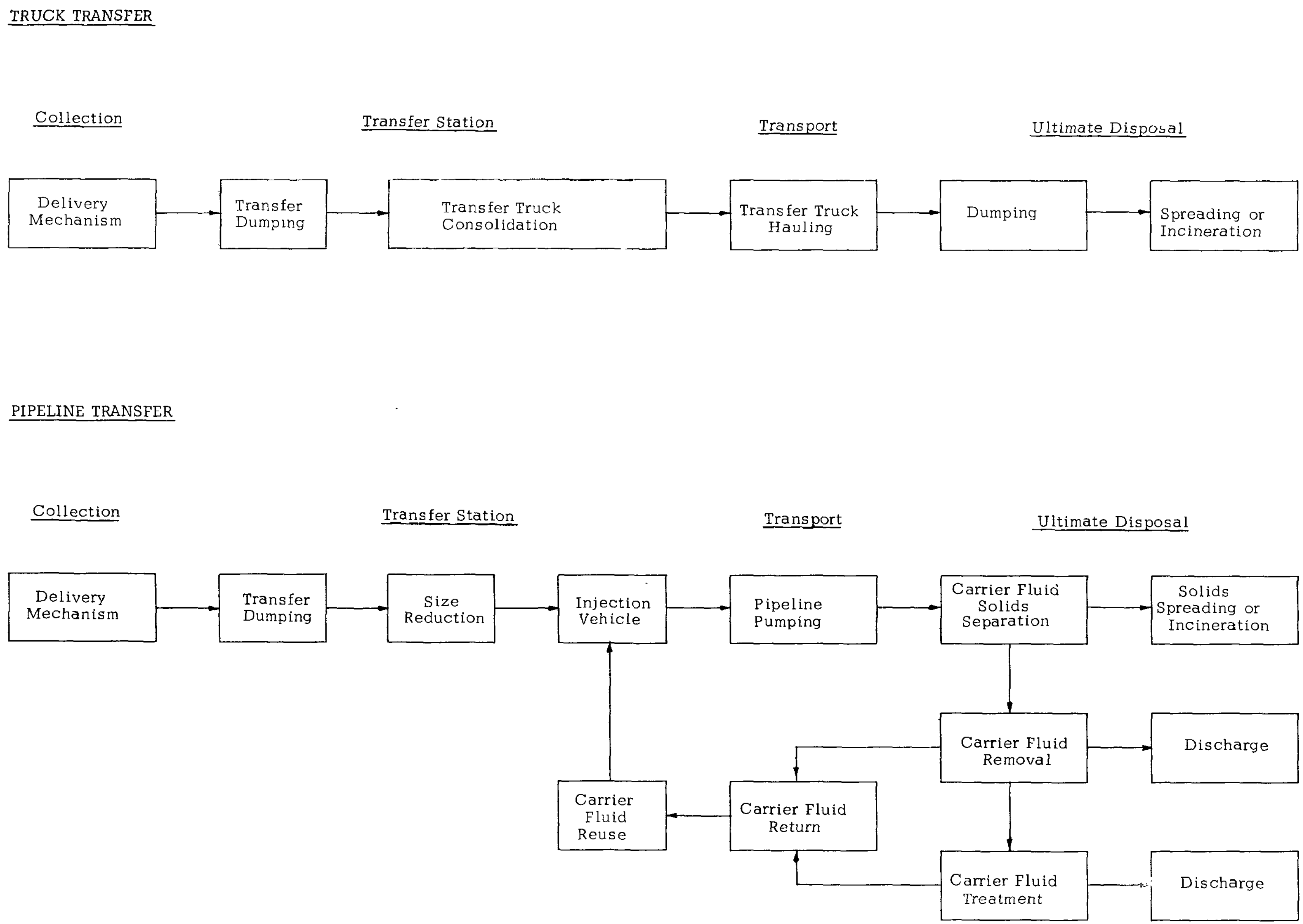

Figure 3. Comparison of Truck and Pipeline Operational Components.

SECTION 4

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APPENDIX A

POLYMER ADDITIVES

Product	Probable Composition	Manufacturer
Percol 139	Polyacrylamide	Allied Colloids
Percol 155	Polyacrylamide	Allied Colloids
Percol 351	Polyacrylamide	Allied Colloids
RC 301	Polyacrylamide	American Cyanamid
RC 322	Polyacrylamide	American Cyanamid
Polyfloc 1100	Copolymer Acrylate/ Acrylamide	Betz Chemical Co.
FR-X	Polyacrylamide	Calgon Chemical Co.
WCL 727	Polyacrylamide	Calgon Chemical Co.
WCL 755	Polyacrylamide	Calgon Chemical Co.
WT 3000	Polyacrylamide	Calgon Chamical Co.
D2-52	Copolymer (Acrylamide)	Calgon Chemical Co.
Separan AP 30	Polyacrylamide	Dow Chemical Co.
Separan AP 273	Polyacrylamide	Dow Chemical Co.
CMC-7H	Cellulose Copolymer	Hercules Corporation
FR 4	Copolymer (Acrylate/ Acrylamide)	Hercules Corporation
NGL 3958	Polyacrylamide	Stein, Hall and Co.
Polyox WSR 301	Polyethylene Oxide	Union Carbide
Polyox Coagulant	Polyethylene Oxide	Union Carbide
Polyox FRA	Polyethylene Oxide	Union Carbide

APPENDIX B

TEST PROGRAM

Discussion

The solid waste sizing tests will be performed using the standardized manufactured solid waste as previously defined. It is imperative that all refuse be tested for initial moisture content before mixing with the test fluid. This moisture may account for up to 30 percent by weight of the refuse. Final slurry concentration determinations will involve drying and weighing of the residue and these must take into account the initial moisture. Each hammermill grate size will result in a distribution of solid waste particle sizes. The material from each grate size will then be used to perform the injection tests for the particular particle size and the flow tests requiring that distribution of particle sizes. The capability and capacity tests of the dewatering equipment will be performed on the exit material from the flow tests. The dewatered solid waste will be disposed of in a sanitary landfill adjacent to the test facility. The carrier fluid will be lagooned nearby for natural oxidation prior to ultimate disposal.

The sizing tests, injection tests, flow tests, and dewatering tests will then be performed in sequence using each of the remaining grate sizes.

After the base information tests have been performed, an analysis will determine the best grate size and the best injection technique for slurry. These will be used for all of the slurry transport tests with polymer.

Gravity transport of the slurry will be performed with the pipe running half full with the velocity varied by changing the slope of the test line.

The slurry will be blended continuously in the mixing tank and gravity flowed into the line.

All slurry transport tests will be performed on a once-through basis with none of the solid waste or carrier fluid being reused. The solid waste will be disposed of in a nearby sanitary fill and the carrier fluid lagooned for future disposal.

The capsule transport tests will be performed on a once-through basis for the carrier fluid with the capsules being reused if there is no contamination of the capsules from broken containers in transport. The capsules will be segregated according to size and fill density and stored between tests.

The capsule transport tests without polymer should reveal the difference caused by either the fill density or the capsule configuration. An analysis will allow the selection of a capsule size and a fill density to be used on the tests with polymer.

The capsule transport tests, with polymers, will also be performed with the carrier fluid discharged to waste. The capsules will be reused if undamaged or not contaminated from prior transport tests.

The carrier fluid reuse tests will be performed by collecting and returning the carrier fluid to the mixing tank. It will then be mixed with new manufactured solid waste and measurements of flows, velocities and losses made as before.

TEST PLAN

Base Information

Grinder Tests - 9 Tests

1 in. grate size, 3 tests of 20 min. each
2 in. grate size, 3 tests of 20 min. each
3 in. grate size, 3 tests of 20 min. each

Classify outputs on each test - use these outputs in performing injection tests.

Injection Tests - 15 Tests

Through Pump

1 in. grate output

3 percent solids concentration rate
5 percent solids concentration rate
10 percent solids concentration rate

2 in. grate output

2 percent solids concentration rate
6 percent solids concentration rate
8 percent solids concentration rate

3 in. grate output

1 percent solids concentration rate
4 percent solids concentration rate
9 percent solids concentration rate

Eductor Method

1 in. grate output

3 percent solids concentration rate
6 percent solids concentration rate

2 in. grate output

1 percent solids concentration rate
4 percent solids concentration rate

3 in. grate output

2 percent solids concentration rate
5 percent solids concentration rate

Flow Tests - 27 Tests

4 Percent Solids

1 in. grate plate

flow velocity 4 ft/sec
flow velocity 8 ft/sec
flow velocity 12 ft/sec

2 in. grate plate

flow velocity 2 ft/sec
flow velocity 6 ft/sec
flow velocity 10 ft/sec

3 in. grate plate

flow velocity 3 ft/sec
flow velocity 5 ft/sec
flow velocity 9 ft/sec

6 Percent Solids

Same matrix as 4 percent

8 Percent Solids

Same matrix as 4 percent

Transport Tests

Water Slurry with Polymers - 54 Tests

First polymer (Use the same test matrix for the second polymer)

10 ppm polymer concentration

slurry concentration 2 percent

velocity 6 ft/sec
velocity 10 ft/sec
velocity 14 ft/sec

slurry concentration 5 percent

velocity 5 ft/sec
velocity 9 ft/sec
velocity 13 ft/sec

slurry concentration 8 percent

velocity 2 ft/sec
velocity 5 ft/sec
velocity 8 ft/sec

50 ppm polymer concentration

slurry concentration 3 percent

velocity 4 ft/sec
velocity 7 ft/sec
belocity 10 ft/sec

slurry concentration 6 percent

velocity 3 ft/sec
velocity 6 ft/sec
velocity 9 ft/sec

slurry concentration 9 percent

velocity 1 ft/sec
velocity 3 ft/sec
velocity 5 ft/sec

100 ppm polymer concentration

slurry concentration 4 percent

fluid velocity 4 ft/sec
fluid velocity 8 ft/sec
fluid velocity 12 ft/sec

slurry concentration 7 percent

fluid velocity 2 ft/sec
fluid velocity 4 ft/sec
fluid velocity 6 ft/sec

slurry concentration 10 percent

fluid velocity 1 ft/sec
fluid velocity 3 ft/sec
fluid velocity 5 ft/sec

Capsule in Water Without Polymer - 81 Tests

Capsule size L/D = 1
Fill density loose fill (10 lb/ft^3)

Capsule spacing - close spaced

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 3 ft/sec

Capsule spacing - 1/2 capsule length between capsule

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 3 ft/sec

Capsule spacing - 50 percent occupied by capsule

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 3 ft/sec

Fill density - 50 percent compacted (15 lb/ft^3)
Same test matrix as loose fill

Fill density - 100 percent compacted (20 lb/ft^3)
Same test matrix as loose fill

Capsule size L/D = 2/1
Same test matrix as L/D = 1

Capsule size L/D = 3/1
same test matrix as L/D = 1

Capsule in Water With Polymer - 54 Tests

First Polymer (Second polymer use same test matrix)

10 ppm polymer concentration

capsule spacing - close

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 3 ft/sec

capsule spacing - 50 percent occupied by capsule

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 4 ft/sec

50 ppm polymer concentration

capsule spacing - close

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 3 ft/sec

capsule spacing - 1/2 capsule length between capsule

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 4 ft/sec

100 ppm polymer concentration

capsule spacing - 1/2 capsule length between capsule

capsule velocity 1 ft/sec
capsule velocity 2 ft/sec
capsule velocity 4 ft/sec

capsule spacing - 50 percent occupied

capsule velocity 1 ft/sec
capsule velocity 1 ft/sec
capsule velocity 4 ft/sec

Second Polymer - same matrix

Water Slurry Gravity Transport - 12 Tests

Flow velocity 1 ft/sec

solids concentration 2 percent

solids concentration 6 percent
solids concentration 8 percent

Flow velocity 2 ft/sec

solids concentration 1 percent
solids concentration 5 percent
solids concentration 9 percent

Flow velocity 3 ft/sec

solids concentration 2 percent
solids concentration 4 percent
solids concentration 8 percent

Flow velocity 4 ft/sec

solids concentration 1 percent
solids concentration 3 percent
solids concentration 7 percent

Water Slurry with Polymer Gravity Transport - 24 Tests

First Polymer (Use the same test matrix for the second polymer)

10 ppm polymer concentration

Flow velocity 1 ft/sec

solids concentration 2 percent
solids concentration 4 percent

Flow velocity 3 ft/sec

solids concentration 2 percent
solids concentration 4 percent

50 ppm polymer concentration

Flow velocity 2 ft/sec

solids concentration 1 percent
solids concentration 5 percent

Flow velocity 4 ft/sec

solids concentration 1 percent
solids concentration 3 percent

100 ppm polymer concentration

Flow velocity 2 ft/sec

solids concentration 5 percent
solids concentration 9 percent

Flow velocity 4 ft/sec

solids concentration 3 percent
solids concentration 7 percent

Carrier Fluid Reuse

Slurry w/o polymer 10 cycles of fluid	1 conc. solid 1 flow velocity 1 particle size
Slurry with polymer 10 cycles of fluid	1 conc. solid 1 flow velocity, 1 polymer conc. 1 particle size
Capsules w/o polymer 10 cycles of fluid	
Capsules with polymer 10 cycles of fluid	

Slurry Solids Concentration Limit

Start at solids concentration of 12 percent and increase concentration by 2 percent steps until slurry cannot be pumped.

APPENDIX C

TEST FACILITY DRAWINGS

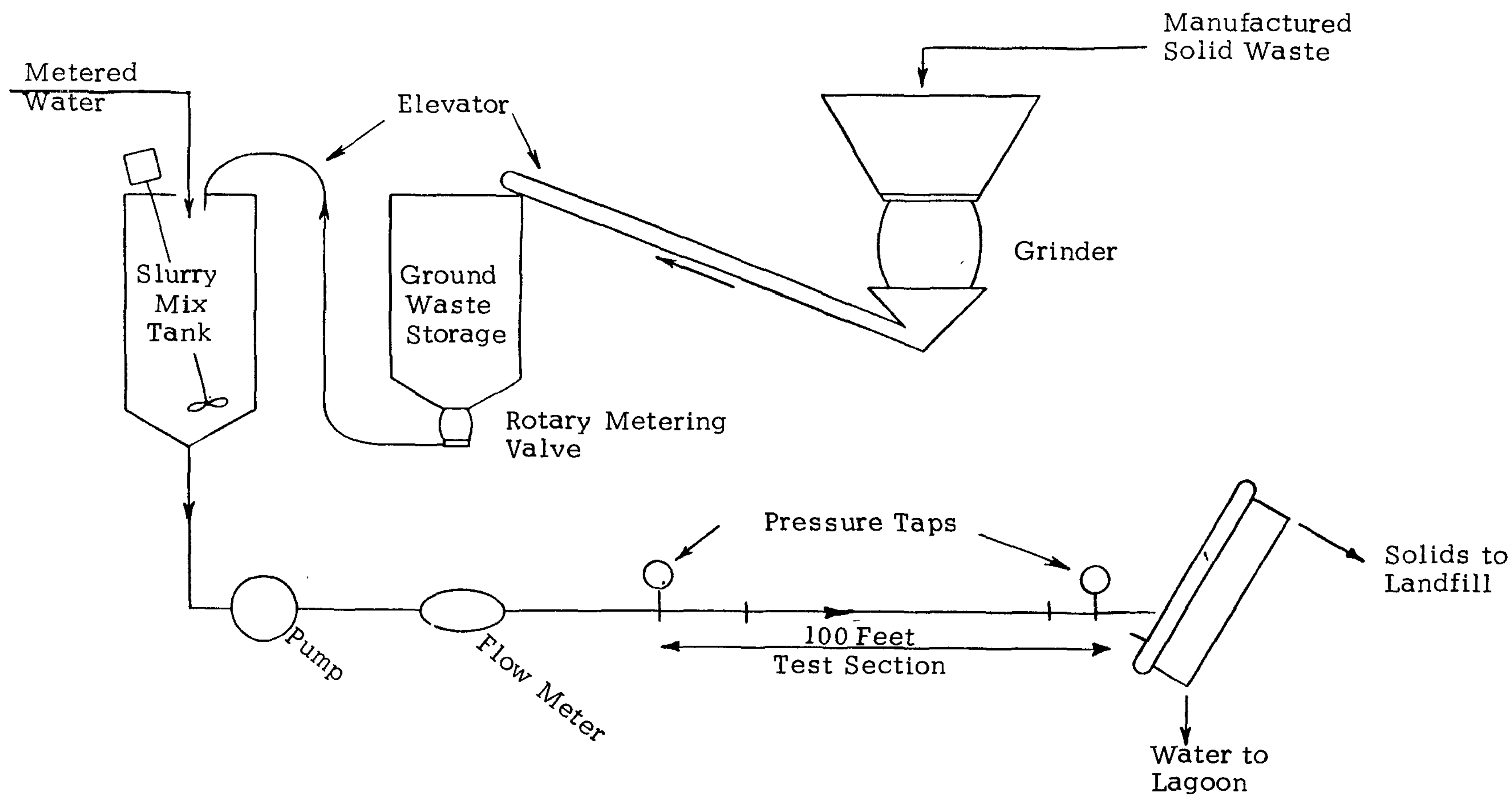

Figure C-1. Schematic Layout of Slurry Pumping Tests

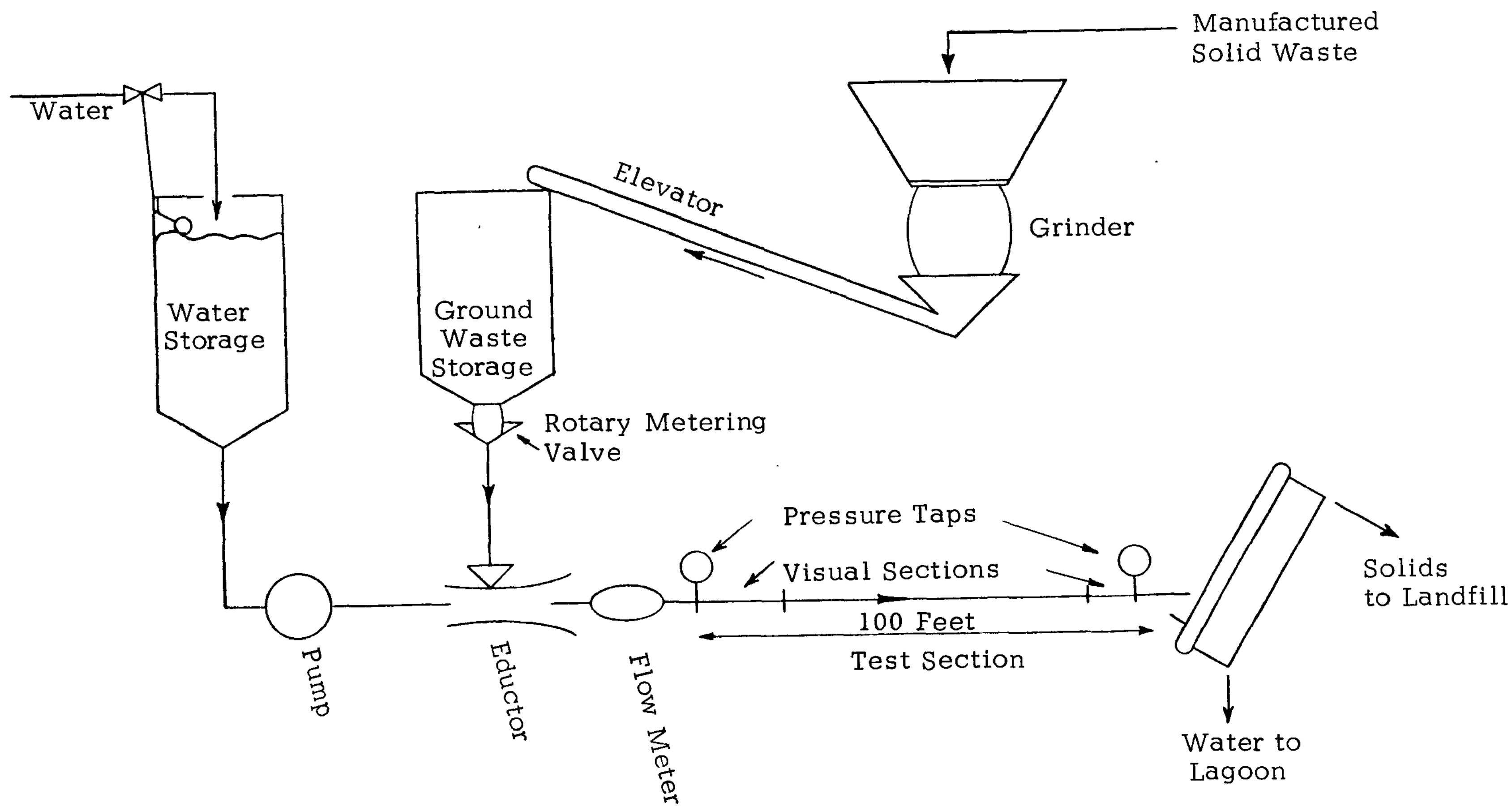

Figure C-2. Schematic Layout of Dry Solids Injection Tests

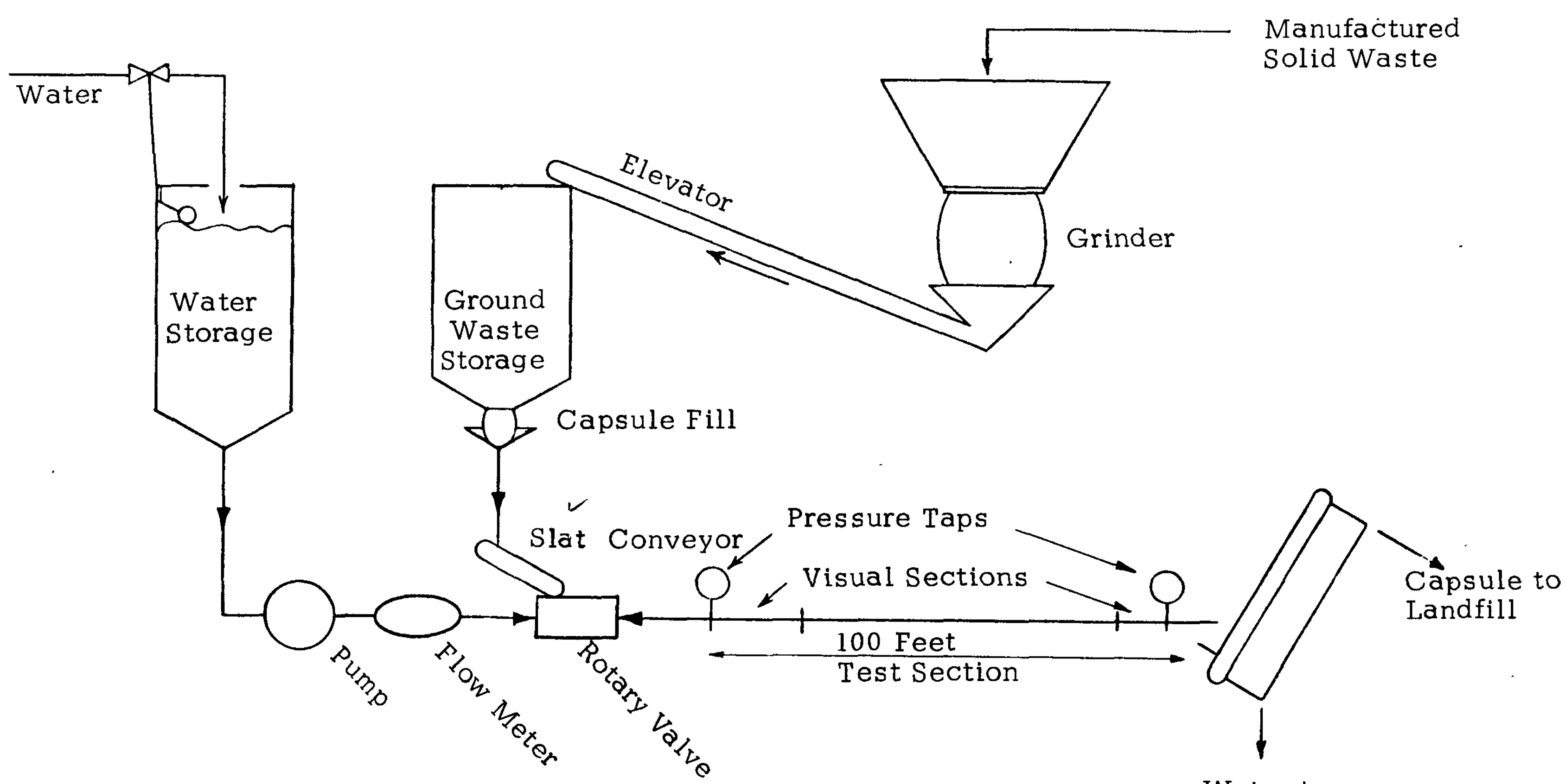

Figure C-3. Schematic Layout of Capsule Insertion Tests

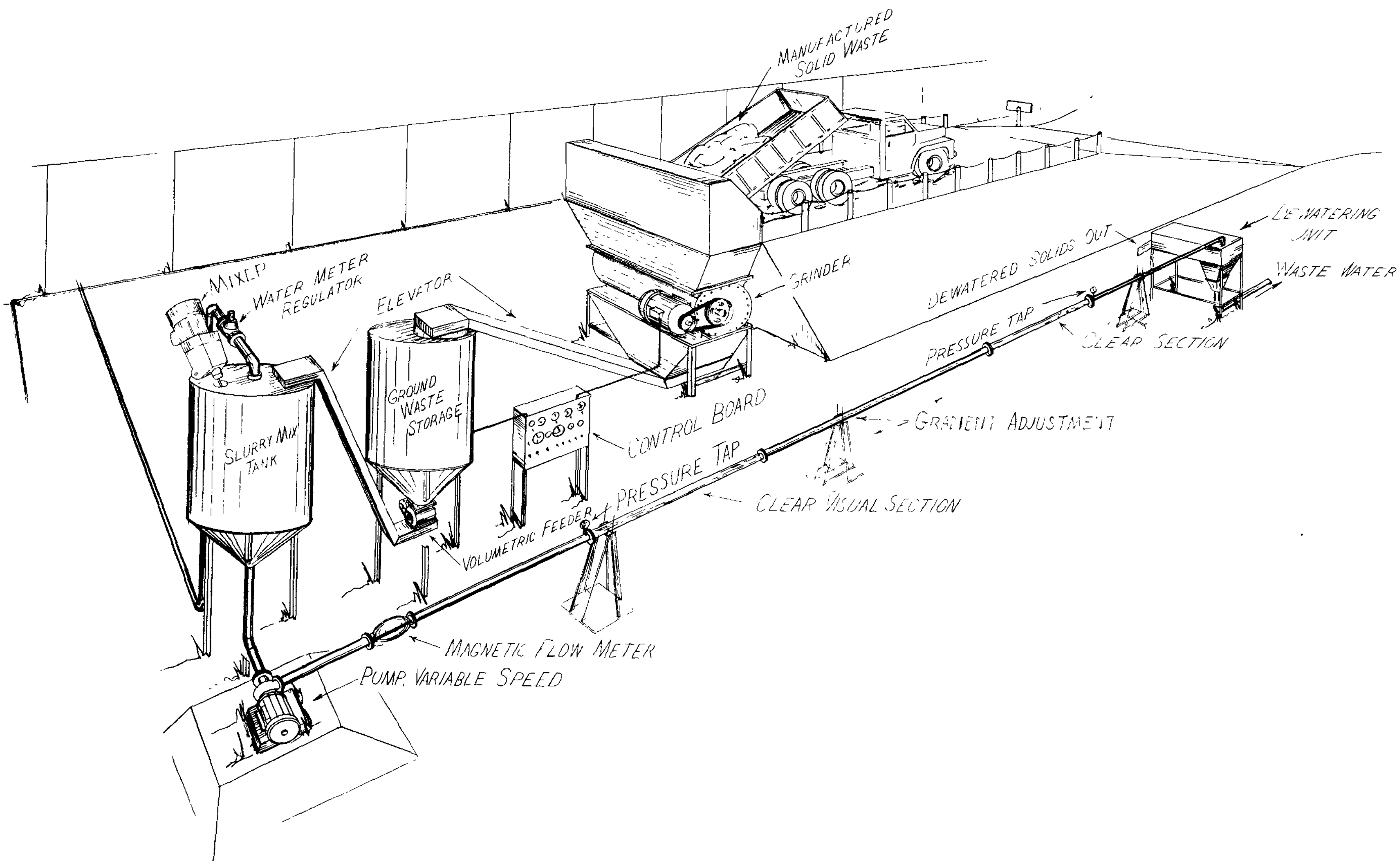

Figure C-4. Equipment Layout for Slurry Pumping Test

TABLE C-1

EQUIPMENT LIST

Item No.	Description	Capacity, Size, Etc.
1	Hammermill	4 tons/hr of solid waste
2	Grinder Feed Hopper	4 cubic yards
3	Elevator, Grinder to Storage	150 lbs/min of 10 lbs/ft^3 material
4	Tank, Ground Waste Storage	2000 cubic feet
5	Rotary Valve	750 lbs/min of 10 lbs/ft^3 material
6	Elevator Ground Storage	705 lbs/min of 10 lbs/ft^3 material
7	Slurry Storage Tank	15,000 gallons
8	Slurry Agitator	7.5 Hp Lightning
9	Pump, 6-in.	100-2000 gpm vs 150-ft head
10	Flow Meter	6-inch magnetic 100-2000 gpm
11	Pressure Transducer (2 ea)	0 - 50. psi
12	Test Flow Pipe	6-in. C.I or steel epoxylined
13	Visual Pipe Sections (2)	6-in. cast acrylic
14	Solids Separator	750 lbs solid/min
15	Dry Solids Eductor	6-in. hopper equipped
16	Slat Conveyor (Capsule)	18-in. wide-Geneva Drive
17	Rotary Valve	14-in. x 20-in. blow-through w/6-in. pipe and Geneva Drive
18	Polymer Injection Pump	Duplex piston 250 gph
19	Polymer Mixing and Storage Tank	300 gallons
20	Water Supply Meter	2 1/2-in. rate indicating

APPENDIX C

TRUCK TRANSFER ECONOMIC ANALYSIS

In 1967, The City of Dallas began definitive planning for the Fair Oaks Solid Waste Transfer Station. The station was designed to service the northeast quadrant of the City where no disposal sites were available. The site has frontage along the Southern Pacific Railroad. Both rail and pipeline movement to ultimate disposal sites were envisioned as potential alternatives to truck transport from this central depository. Operations began in October 1969 utilizing tractor-trailer transport via a peripheral freeway to a sanitary landfill operation on the northwest side of Dallas.

The station was completed and placed in operation at a cost of $400,000 including $50,000 for 19.4 acres of land. Receipts consist of garbage and trash exclusively from three-man crew city collection trucks delivering to the station's three hoppers. Overall design will permit expansion of the facility to six hoppers as future thruput requires.

Transfer operations are carried on five days per week by one foreman, four drivers, one hopper operator, one spotter, one scaleman, and two night watchmen. Four one-man transfer trucks are currently utilized, each having a 60 cubic yard self-packing trailer. A solid waste density of about 500 pounds per cubic yard is achieved using these trailers, and each transfer load has averaged approximately 4.5 collection truck loads. The round trip distance to the disposal site is slightly under 33 miles.

Table D-1 summarizes, quantitatively, the results of the first full year of operation and identifies certain key comparative operational measures. The total cost of operation shown is total direct cost and does not include any allocated overhead or burden. Table D-2 details basic operational data on a monthly basis.

It is the general feeling of Dallas officials that this data represents a relatively accurate long term picture of the operation. Some efficiencies and a reduction in cost are expected with increased operating experience and growing volume, but those are expected to be partially offset by some inflation in basic costs, primarily labor.

The cost of $2.83 per ton and $0.09 per ton mile compares favorably with most previous data available from published studies in other geographic areas of the United States. This data, which also typically combines station and haul operations, is highly dependent on local operating conditions, which can vary dramatically. However, some overall consistency is apparent. Costs developed in central California range from under $1.00 through $2.60 per ton and from $0.05 to $0.10 per ton mile, while in Maryland they were found to range from $1.50 to just under $3.00 per ton and from $0.08 to $0.13 per ton mile. Comparable systems in the suburban Detroit area are found to fall within the same ranges. Obviously, alternatives to truck transport, which tend not to be as variable with local operating conditions, must be justified economically on an installation by installation basis as the available data suggests.

The Fair Oaks truck transfer operation in Dallas was originally justified on the basis of savings in total rolling stock investment and associated labor costs. No substantive data is yet available on how well the system measures up to that objective, but, on the basis of the first year's operation, it is generally felt that a decrease in total truck investment will be achieved. As Table D-2 indicates, the transfer ratio has been steadily improved and a ratio of about 5.0 has probably been achieved on a permanent basis. This ratio alone has an important impact on rolling stock investment.

TABLE D-1

FAIR OAKS SOLID WASTE TRANSFER OPERATIONS
NOVEMBER 1969 - OCTOBER 1970
SUMMARY

Total transfer truck cost			$ 43,600
Direct driver cost[1]			24,750
Transfer hauling cost			68,350
Direct transfer station operating cost			32,854
Total direct cost of operations			$101,204
Tons transferred			35,813
Average tons per working day			138
Loads received			10,599
Loads transferred			2,410
Transfer ratio (loads received/loads transferred)			4.4
Miles driven in transfer			79,286
Manhours employed			20,891
Hours of equipment downtime			470
Average transfer mileage, round trip			32.9
	Station	Hauling	Total
Cost per ton	$.92	$1.91	$2.83
Cost per ton per mile	.03	.06	.09
Truck cost per mile[2]	-	.55	.55

[1]Mean driver wage of $2.98 per hour.

[2]Does not include driver cost.

TABLE D-2

FAIR OAKS SOLID WASTE TRANSFER OPERATIONS

FIELD OPERATIONS - PUBLIC WORKS DEPARTMENT - CITY OF DALLAS

NOVEMBER 1969 - OCTOBER 1970

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
Cost of Operation	$9,082	$12,026	$8,494	$7,914	$9,748	$8,270	$7,964	$9,595	$8,714	$9,882	$7,979	$8,611
Tons Transferred	2,673	3,417	2,479	2,346	3,464	3,266	3,380	3,822	3,572	3,495	3,593	3,312
Loads Received	839	1,057	823	709	1,017	917	902	994	1,045	1,193	980	984
Loads Transferred	215	260	210	169	226	219	203	214	223	243	197	200
Transfer Ratio (Received/Transferred)	3.90	4.07	3.92	4.20	4.50	4.19	4.44	4.64	4.69	4.91	4.97	4.92
Miles Driven	7,957	10,393	6,676	5,655	7,342	6,782	6,458	6,936	6,897	6,444	6,362	6,358
Manhours Worked	1,723	2,289	1,797	1,705	2,088	1,593	1,525	2,098	1,906	2,236	1,684	1,799
Equipment Downtime	40	21	48	19	68	119	18	35	9	6	79	2
Cost Per Ton	$3.40	$3.52	$3.43	$3.37	$2.81	$2.53	$2.36	$2.51	$2.44	$2.83	$2.22	$2.60