

DEVELOPMENT OF REFUSE DERIVED FUEL (RDF) PELLETS AND IMPLICATIONS FOR THE LIME INDUSTRY

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1 INTRODUCTION

The disposal of refuse is a matter of increasing concern for municipalities and state governments throughout the U.S. In a 1987 report to Congress, the U.S. Environmental Protection Agency (EPA) estimated that the nation generated approximately 185 million tons of municipal solid waste (MSW) in 1990.¹ Further, it was projected that the amount of municipal waste generated by the year 2000 will be 160-290 million tons per year. As existing landfills become filled to capacity and new landfills more costly to site, the development of alternative disposal methods is becoming critical. In addition, the refuse being buried contains considerable quantities of energy that can replace conventional fossil fuels. Some of the main problems of using refuse for fuel have been the poor quality of the fuel, its variability, and its biological and chemical instability.

An improved method for turning refuse into an environmentally safe and economical fuel has recently been developed by researchers from Argonne National Laboratory (ANL). In this method, recyclable metals, glass, and some plastics are separated from the refuse. The remaining (combustible) fraction is combined with an alkaline earth metal hydroxide, in this case a calcium hydroxide binding additive and formed into cylindrical pellets. These pellets are hard and odorless, can be stored for up to three years without significant biological or chemical degradation, and due to their increased bulk density, are more durable and can be more easily transported than other types of waste-derived pellet fuels.

The other, and possibly more important, benefits of the refuse-derived fuel developed by ANL, include significant reductions of sulfur oxides (SO_x), nitrogen oxides (NO_x) and CO_2 in the flue gases, and the trapping of the chlorine combustion products such as HCl that are formed from the remaining plastics in the refuse. This makes the pelletized binder-enhanced RDF (b-dRDF) a part of the environmental solution, rather than a part of the problem.

The feasibility of producing a b-dRDF pellet has been demonstrated in the laboratory and in a large-scale pilot plant test conducted by ANL, and the U.S. Department of the Navy at a Naval Air Station at Jacksonville, Florida. Full-scale commercial fabrication of over 600 tons of b-dRDF pellets was completed at two processing facilities: Reuter Inc. and Future Fuels, Inc. The commercially produced pellets gave very good agreement with the experimental results obtained during the laboratory and pilot-scale tests. Subsequent full-scale combustion tests with cofired b-dRDF pellets and coal were conducted at ANL in a large 170,000 lb/hr (20 MWe)

spreader-stoker utility boiler. These tests verified the predicted reduction of SO_x, NO_x, and CO₂ in the flue gas and the reduction of heavy metals and organics in the ash.

Considerable industrial, state, and federal participation was involved in critiquing the full-scale combustion test plan and witnessing of the actual test runs. Subsequent interest in the use of b-dRDF pellets as an alternative fuel source is indicated by the more than 370 requests for the test reports. A collaborative effort between ANL, the U.S. Department of Energy, the British Department of Energy, and Warren Spring Laboratory of the U.K. was initiated to fabricate b-dRDF pellets in England and test the emissions resulting from the combustion of the b-dRDF pellets both in combination with coal or when fired alone.

Firing of b-dRDF pellets with coal in existing coal-fired spreader stoker boilers can be accomplished with little or very minimal physical modifications to be made to the boiler and its ancillary systems. A recent EPRI study² indicates that between 1972 and 1984, nine utilities conducted short term co-firing tests of RDF with coal. Results of these tests have indicated that:

- Boilers can be modified at relatively low cost to accommodate co-firing of coal and RDF
- Co-firing of coal and RDF requires relatively minor alterations in the operation of the combustion equipment
- Air pollution control equipment which functions for coal will also function with acceptable efficiencies for co-firing of coal and RDF.

ANL has recently conducted pilot-scale tests in which it has been demonstrated that b-dRDF pellets can also be successfully fired with coal in suspension fired boilers by pulverizing both the pellets and coal at the same time in a common pulverizer prior to firing. Alternatively, Reuter has developed a "flake" type of RDF which is typically 3/8-1/2" in size and has a bulk density of about one-half that of coal. This "flake" configuration is formed by compressing the basic RDF substrate. This type of RDF should also be suitable for co-firing with coal in suspension-fired boilers.

This paper describes the b-dRDF pellet/coal cofiring tests at ANL, the sampling and analysis test program, and study conclusions. A discussion is given as to the intended market for the technology during the 1995-2010 time frame and the implications which this technology has on the lime industry.

2 BACKGROUND

As part of Argonne's Energy from Municipal Waste Program, ANL conducted a multi-phase research study on the use of low-cost binder additives for improving b-dRDF pellets. The laboratory test phase of this study, which was completed in 1985, examined over 150 potential binders and binder combinations.³ Each binder was ranked on the basis of a series of criteria, including cost, environmental acceptability, and effectiveness. Many binder candidates were

quickly eliminated by this ranking procedure.⁴ Approximately 60 were subjected to a more detailed analysis, including laboratory testing.

The 13 most promising candidates from this laboratory testing and analysis were selected for field testing. The field work, witnessed by industry, was conducted during 1986 at the Naval Civil Engineering Laboratory's test facility at Jacksonville Naval Air Station, Florida. The pellets that were produced from fifty-three individual test runs were subjected to a battery of chemical and physical tests, which indicated that calcium hydroxide was the top-ranked binding agent.

As the third and final phase of the multi-phase study, ANL conducted full-scale combustion tests of binder enhanced dRDF pellets and high-sulfur coal. These tests were conducted during June and July of 1987 in ANL's Boiler #5.

3 STUDY APPROACH

Binder-enhanced dRDF pellets were blended with Argonne's normal high-sulfur (about 2.7% S) coal at 10, 20, 30, and 50% on the basis of Btu content. When steady-state operation was attained for each blend, data samples were taken for mass and energy balances, emissions characterizations, and ash analyses. Baseline evaluations were conducted with 100% coal at the beginning and at the conclusion of the test program. One hundred percent coal burning was also conducted between the firing of each of the blend ratios to minimize possible carryover effects from the previous test. Dust blowing of the boiler was conducted and completed either just prior to or at the completion of each test run. The condition of the facility during testing can be considered normal because the facility did not require either special maintenance or any physical modifications before the test program. However, other, concurrent tests at the facility made available computerized data logging equipment and an unusually high amount of process monitoring information.

4 RDF FUEL PREPARATION

Two possible sources for obtaining the required quantity of b-dRDF pellets were identified: a small (60-80 ton/day) dRDF processing facility at Thief River Falls, Minnesota, and a 400 ton/day facility at Eden Prairie, Minnesota.

The b-dRDF pellets that were fabricated at the Thief River Falls facility were produced during November and December of 1986 and were stored inside the facility. The pellets were produced in three lots with binder contents of 0, 4, and 8% by weight. A total of 225 tons of b-dRDF were produced. The Thief River Falls facility, which uses Lundell processing equipment, had been in operation for approximately one year at the time the pellets were made. The equipment for adding the binder additive to the RDF substrate was designed, built, and installed by the Lundell company as part of their contribution to the project.

An additional 352 tons of pellets were supplied by the Rueter facility located in Eden Prairie, Minnesota. The pellets were produced in five lots, with three lots containing binder

contents of 0, 4, and 8% by weight, identical to the three lots of b-dRDF pellets fabricated at the Thief River Falls, Minnesota facility. Two additional lots were prepared, each with approximately 95% of the PET and HDPE plastics removed and with binder contents of 0 and 4% by weight. This processing facility uses equipment manufactured by Buhler-Miag, Inc.

5 TEST FACILITY DESCRIPTION

Boiler Configuration

The boiler plant at ANL consists of five boilers that provide steam for the entire laboratory. Although the steam is used primarily for space heating, the steam is also used for refrigeration and possibly for driving emergency electrical turbo generators. Boiler No. 5, the boiler used for this research program, is a spreader-stoker unit with a capacity of 170,000 lb/h of 200 psig saturated steam, the equivalent of about 20 MW_e. At 170,000 lb/h, the coal use (based on 11,6700 Btu/lb) is 9.0 ton/h; at one-half rated capacity (85,000 lb/h), the coal use is 4.49 ton/h. The maximum operational firing rate, equivalent to producing 130,000 lb/h steam, is about 144.4×10^6 Btu/h. This boiler was installed in 1965 by the Wickes Boiler Company (now Combustion Engineering Company) and was converted to gas/oil firing in 1973. In 1979, the boiler was reconverted to coal firing with the expectation of burning high-sulfur (nominally 3.5%), Illinois-basin coal. Because the original emissions control equipment consisted of only a multiclone particulate-matter collector, additional SO₂ control was required. A number of possible flue-gas cleanup (FGC) systems were evaluated and spray-dryer technology was selected on the basis of several factors, including system simplicity and dry-waste production. A schematic of the steam-generating equipment and air pollution control devices is shown in Figure 1.

Air Pollution Control Equipment

The air pollution control equipment for the test boiler consists of a mechanical multiclone collector, a spray dryer absorber, and a fabric filter baghouse. The multiple cyclone, which was manufactured by Western Precipitation, Inc., contains 105 cyclones and has particulate-matter removal efficiencies of 80% and 90% for gas flow rates of 50,000 and 25,000 standard ft³/min, respectively.

After the flue gases exit the multiclone collector, they enter the spray-dryer absorber (SDA) through a system of two gas dispensers. After passing through the dispenser, the flue gas contacts a fine spray of absorbent (lime and recycled waste powder feed slurry). Sulfur dioxide is absorbed into the alkaline droplets as water is simultaneously evaporated, cooling the flue gas. Control of the gas distribution, slurry feed rate, temperature, and pressure assures that the reacting droplets reach the desired dryness before they leave the SDA chamber. A portion of the dry product, consisting principally of fly ash, calcium sulfite, calcium sulfate, and unreacted lime, falls to the bottom of the absorption chamber. The material is then conveyed to a storage silo, where it is held for recycle or disposal in the ANL landfill.

The treated and cooled flue gases leave the SDA module and flow to the fabric-filter baghouse. The baghouse system provides particulate-matter collection and also contributes

significantly to the removal of SO₂ as the flue gas passes through the dust cake on the bags. Particulate matter collected in the baghouse is also conveyed to the recycle storage silo.

6 TEST PROGRAM

b-dRDF Pellet Handling and Storage

Approximately 225 tons of b-dRDF pellets (both with and without a binder additive) from the Thief River Falls facility were delivered by covered truck (approximately 22 tons capacity each) to ANL as needed for the tests shown in Table 1. An additional 352 tons of b-dRDF pellets supplied by the Reuter facility were also tested. Lundell Manufacturing, Inc., and Reuter, Inc., contributed the costs of shipping the pellets from Thief River Falls, Minnesota, to ANL, and from Eden Prairie, Minnesota, to ANL, respectively. Buhler-Miag, Inc., contributed the cost of setting up the binder-handling facility at the Reuter facility, as well as the associated engineering costs.

The handling of the b-dRDF pellets was kept to a minimum, because excessive handling will result in considerable breakage of the pellets. The durability of the pellets is a direct function of their bulk density. Also, allowing the fuel to fall long distances (e.g., from conveyors to the ground, or to another conveyor) will tend to degrade the mechanical properties of the pellets. The b-dRDF was delivered by 26 trucks over the course of the program to minimize storage before conducting a test. All truck loadings and unloadings were observed by ANL or UNT test personnel to ensure that the handling of the fuel was kept to a minimum and that canvas covers were installed on the trucks to keep the fuel dry in transit.

After delivery, the pellets were stored outdoors adjacent to the ANL coal-handling facilities and were covered by anchored canvas or polyethylene tarpaulin to ensure that the dRDF pellets were not exposed to the elements. The protection cover, however, had the disadvantage of preventing the moisture from evaporating out of the pile. This moisture condensed, causing a moist layer of b-dRDF on the surface of the pile. This problem was minimized by removing the cover prior to the coal-blending process to allow the outer layer to dry. Transfers of the b-dRDF pellets from the storage area to the coal-blending area were made, test schedules permitting, during dry weather.

Coal-Blending Operations

A trial test firing of approximately 8.5 tons of b-dRDF pellets obtained from the Thief River Falls facility was conducted at ANL during early May 1987. Much was learned about the blending of b-dRDF with coal during this short test. For example, mixing three volumes of coal and one volume of b-dRDF pellets with a four-cubic yard front-end loader produced a blend that was close to 10% dRDF by Btu content. It was determined that four turnings of the coal/dRDF mixture produced a very homogeneous blend.

This trial burn allowed procedures to be developed to determine the quantity of coal that was placed in the boiler's feed bunker daily and the length of time and quantity of coal burned per hour as a function of the energy demand.

7 SAMPLING METHODS AND ANALYSIS

Over 800 samples (as shown in Table 2) of the flue-gas emissions, flyash, bottom ash, and feedstock were collected during the 12 test runs given in Table 1. These samples were taken at the sampling station locations shown in Figure 1. Analysis of the data from these tests were performed by ANL in cooperation with the University of North Texas.⁵

8 STUDY CONCLUSIONS

Densified b-dRDF pellets containing a calcium hydroxide binding agent have demonstrated the following important advantages over conventional dRDF pellets fabricated without a binder additive.

1. Bulk density is a good indicator of the mechanical strength and durability of dRDF pellets. Pellets fabricated with a calcium hydroxide binding agent have consistently demonstrated, both in the laboratory and when fabricated commercially in large quantities (i.e., hundreds of tons per day), bulk densities 75% greater than pellets without a binder. This increase in bulk density allows the pellets to be more easily transported and minimizes handling and conveying problems when firing the pellets (Figure 2).
2. The use of calcium hydroxide as a binding agent allows the pellets to be stored outside for a period of six months without biological and chemical degradation. Conventional dRDF pellets without a binder cannot tolerate outside storage periods of longer than four to five days without suffering substantial chemical and biological degradation (Figure 3).
3. Pellets containing a calcium hydroxide binding agent can be stored inside for indefinite periods without biological and chemical degradation. Such pellets have been stored at ANL for over three years. Pellets without a binder agent show visual biological degradation within two to three weeks.
4. b-dRDF pellets containing a calcium hydroxide binding agent contain 2% fewer -3/8 fines than conventional b-dRDF pellets without a binding agent. This reduction means less bridging and jamming in feed hoppers and conveying systems. Fewer fines also means fewer agglomeration problems when stored in feed hoppers and fewer "dusting" problems when pellets are being transported or conveyed.
5. The optimum moisture content when pellets are fabricated without a binding agent varies between approximately 15 and 20%. For moisture contents greater than 20%, it is not possible to produce even a marginal-quality pellet. With a calcium hydroxide binding agent, quality pellets can be produced with moisture contents up to and including 36%. Because considerable drying of the RDF substrate is necessary to reduce the moisture content to a maximum

of 20% for conventional dRDF pellets, a substantial energy savings is realized by producing pellets containing calcium hydroxide (Figure 4).

6. Uncontrolled (prior to pollution control devices) sulfur dioxide (SO_2) flue gas emissions decreased from the coal baseline of 1,600 ppmv as blend ratios of dRDF/coal increased, and as the binder percentage was increased (Figure 5).
7. Uncontrolled nitrogen oxides (NO_x) flue gas emissions decreased from the coal base line of 300-350 ppmv as blend ratios of dRDF/coal increased and as binder percentage increased. The data fluctuated; however, general trends are shown in Figure 6.
8. The uncontrolled hydrogen chloride (HCl) flue-gas emissions increased above the coal baseline of 15 ppmv when dRDF/coal blend firing rates were increased. However, the uncontrolled HCl flue-gas emissions were reduced as the amount of lime binder was increased from 0 to 8%. For example, i.e. at a 30% dRDF/coal blend and 8% binder, the HCl emissions were approximately 32 ppmv. With a removal efficiency of 95%, the HCl emitted to the atmosphere was well below the proposed EPA control level of 25 ppmv (Figure 7).
9. The CO_2 emissions were reduced by the addition of a binding agent. At a 4% binder addition, the CO_2 emissions were reduced approximately 5% compared to b-dRDF without a binder additive, while an 8% binder resulted in a reduction of approximately 10% (Figure 8).
10. No detectable concentrations of bromides or fluorides were found in the flue-gas emissions at sampling locations 9 or 10. Detection levels were 2.5 ppmv for HF and 2.0 ppmv for HBr.
11. The concentration ranges for toxic metals in the flyash and bottom ash were significantly lower (and in some cases orders of magnitude lower) than levels typically found in mass burn facilities.
12. All total tetra through octa chlorinated dioxins and furans were below the detection levels for all flue-gas samples taken at the stack.
13. A definite decrease in PAH and PCB emissions was observed with increasing binder content in the pellets.
14. All flyash samples tested were below the detection levels for total tetra through octa chlorinated dioxins and furans.
15. Bottom ash and flyash samples from all test runs passed the EP Toxicity tests. A total of 103 flyash samples and 113 bottom ash samples were analyzed. It

is important to note that lead and cadmium, which have been found to fail the EP tests in many cases involving the mass burning of municipal solid waste, were not found to exceed the limits of 5 and 1 mg/L, respectively, in the leaching solution.

16. The test results show that b-dRDF pellets can be fed along with coal to an existing stoker-fired boiler at rates up to 50% dRDF (by heat input) without upsetting combustion stability or the ability of the boiler to maintain load demand. Modifications to the system could permit firing at dRDF rates in excess of 50%. According to our studies, firing rates in excess of 50% should present no boiler operational problems if relatively minor modifications are made to the boiler (e.g., feed and ash handling system capability increased). Fuel handling, slagging, and clinkering problems were not noticeably worse than when firing only coal.
17. Visually, the carry-over of particulate matter from the furnace into the convection bank of the boiler did not appear to be significantly greater than when firing coal alone. "Sparklers" were rarely evident. When dRDF fuel was bunkered with coal, the refuse material could be handled without incurring housekeeping problems in the boiler plant. Some minor odors were reported by the operating personnel.

9 POTENTIAL MARKETS

The opportunities for the co-firing of b-dRDF pellets and coal exist in almost every segment of our economy. As an example, co-fired facilities can be used in the food, agriculture, manufacturing, chemical, and textile industries, the electric utility industry, at military sites and in institutional and commercial settings. There certainly do not appear to be any insurmountable barriers to the implementation of co-firing in any sector of the economy.

Where are the most likely markets for expansion of co-firing of b-dRDF and coal blends? Certainly, as we will see in the following sections, the electric utility industry offers the most attractive opportunity for the use of co-firing both at existing facilities and for future applications. At the present time, several very large utility companies in the Midwest and northeastern regions of the U.S. are either currently co-firing (RDF/coal) or seriously considering the expanded use of fossil fuels co-fired with RDF.

Food processing and agricultural industries have been quite active during the past 20 years in developing systems to co-fire their waste products for energy recovery and to reduce the expense of waste disposal. The same positive incentives exist in the manufacturing, chemicals and textiles sectors of the economy. It is very likely that the trend toward increased co-firing of b-dRDF and coal will continue in all of these economic sectors. There is no indication that strong negative influences are developing which would deter increased use of waste products for energy recovery. Military facilities are under pressure to reduce expenses and to develop and implement systems for waste energy recovery. Many military installations have boiler facilities which can be

adapted for co-firing of b-dRDF generated on site as well as for co-firing of purchased fuels including refuse based fuels. It is therefore likely that incidence of co-fired fuels will expand at military installations throughout the country during the next decade.

Private institutional settings such as hospitals, universities and college campuses can expect to see some increase in the use of co-firing during the next decade but only in those locations where the economic return is quite good and the capital investment requirements are small. This conclusion is based on the knowledge that many private institutions have limited capital resources available and typically will place co-firing projects low on the priority list unless the economic return is quite high.

State and federally owned institutional settings will also see some scattered increase in co-fired facilities but the expanded use of co-firing will continue to be limited by economic institutional barriers. State and federal sites for the most part have no economic incentive to adopt co-firing.

After examining the various possible markets described above for developing the expansion of b-dRDF and coal co-firing we have concluded that the electric utility industry offers the most attractive market sector to pursue. The following reasons are offered to substantiate this decision:

- As can be seen in Table 3, the total coal that will be consumed by the U.S. economy in 1995 is estimated to be 21.9 quads of energy or 1034×10^6 tons. The amount of coal that will be consumed by the electric utility industry alone is estimated to be 19.3 quads or 912×10^6 tons, or about 88% of all the coal consumed by the U.S. The other segments of the economy (residential, commercial, and industrial) will consume the remaining 12%. This ratio is estimated to remain essentially constant thru the year 2010. From these figures, it is readily apparent that the electric utility industry represents a very large market for the substitution of b-dRDF pellets for coal.

Coal supplies 56.9% of all the electrical power that is produced by the electric utility industry as shown in Table 4.

- Approximately 75% (983 of a total of 1330) of the coal-fired boilers used in the electric utility industry in 1981 are located in three federal regions, Middle Atlantic (Region III), Great Lakes (Region V), and Southeast (Region IV).⁶
- Two of the three federal regions with the largest population of coal-fired boilers are located adjacent to the borders of the U.S. and Canada, where the acid rain problem is most severe. Again, substitution of b-dRDF pellets, at approximately 20% by heat input would substantially reduce the SO₂ and NO_x elements in this area.

- Additionally, about 70-80% of the nation's solid waste is generated in these same federal regions.⁷ This allows the feedstock preparation facilities to be constructed close to where the majority of coal-fired boilers are located, thus minimizing transportation costs.
- A large number (400-500) of the stoker-fired boilers presently in use in the electric utility industry are approaching their design lifetimes of 40 to 60 years. These boilers tend to be much smaller in MW capacity than the newer suspension-fired boilers, roughly 50-75 MW. These units are ideally suited to the co-firing of b-dRDF pellets with coal. Also, the industry is reluctant to dispose of these units and are examining the possibility of repowering or retrofitting the units to co-fires b-dRDF with coal. This is one of the more important reasons why the electric utility industry was selected as the primary market for use by the proposed technology.

10 COMMERCIALIZATION OF b-dRDF PELLET TECHNOLOGY AND ITS IMPACT ON THE LIME INDUSTRY

As described in Section 9, the primary market for the use of the b-dRDF pellet technology has been identified as the electric utility market. It is anticipated that this market sector will be the targeted market during the 1995-2010 commercialization time frame, both for retrofitting existing boilers, and for future new facilities, which are planned for the electric utility industry. A secondary market, which also seems quite attractive as a fossil fuel replacement application is the cement industry, although the coal usage in this market is an order of magnitude less than that of the electric utility market.

To estimate market potential, we have arbitrarily established a number of conservative assumptions. The major assumptions that were made are:

- The commercialization time frame was assumed to be 1995 thru 2010.
- 20% of the average municipal solid waste generated during the fifteen year time period (1995-2010) was assumed to be processed in RDF facilities.
- The b-dRDF pellet yield is assumed to be 45% percent of the incoming waste stream.
- The heating value (HHV) of the pellet is 7,800 Btu/lb.
- Lime additive is 5% by weight of the pellet.
- The b-dRDF pellet substitution rate is 20%. That is, the b-dRDF pellets replace 20% of coal usage on a Btu basis at the various coal fired electric utility plants that would be used to fire the b-dRDF/coal blended fuel.

- The electricity utility market penetration is 10%.

The U.S. EPA has estimated that the nation will generate approximately 225×10^6 tons of municipal solid waste (MSW) in 1995 and approximately 400×10^6 tons of MSW in 2010, or an average of 312.5×10^6 tons/year of MSW during the period 1995-2010, which is considered to be the time frame in which the b-dRDF technology will be commercialized. Assuming that 20% of the average MSW generated would be processed in RDF facilities, yields of 62.5×10^6 tons per year of MSW would be diverted to RDF processing facilities.

The commercial version of the b-dRDF processing facility is assumed to have a capacity of 800-1500 TPD (tons per day) of incoming raw unprocessed MSW. With a yield of b-dRDF pellets to incoming waste of 45%, an availability factor of 0.68 (250 days per year), and using an average facility size of 1150 TPD, approximately 129,375 tons per year can be produced.

The projected size range for the RDF processing facility is not without precedence since there are 47 RDF processing facilities currently in operation or which will be operational in 1991. Most of these facilities produce a "fluff" type of RDF, but can easily be adapted to produce a b-dRDF or powdered RDF by the addition of a binder additive metering device and a pellet mill, or in the case of powdered RDF a ball mill in lieu of the pellet mill. The 47 RDF facilities have a capacity throughout of 100-3000 TPD with the majority in the range of 1000-3000 TPD.

A schematic of the commercial version of a b-dRDF facility is shown in Figure 9. As can be seen, the facility employs a number of mechanical processes that have two basic functions: sizing, homogenization, and separation of the MSW components. As noted, the MSW is first delivered to the processing floor by collection trucks. Large or hazardous items are then removed. Although not shown, the refuse is then classified, is usually manually, for recyclable items. The refuse then goes to a primary shredder. After initial sizing, the refuse passes in turn through a magnetic separator, an air classifier, trommel, secondary shredder, a binder additive metering device (not shown), and finally a pellet mill, where the material is densified into solid fuel pellets.

The b-dRDF pellets produced as described above can be co-fired with coal in various blends by heat input in existing traveling grate, spreader stoker coal fired and pulverized coal boilers.

A powdered RDF fuel product suitable for use in firing either with coal or alone in suspension fired boilers can be, and have been, fabricated by a number of methods. Probably the simplest, and one which involves no additional cost, is to blend the b-dRDF pellets with coal and pulverize both the pellets and coal at the same time in the pulverizing equipment that is normally used for pulverizing the coal. Argonne National Laboratory (ANL) has recently conducted pilot-scale tests in which this technique has been demonstrated very successfully. Alternatively, the Reuter Company has developed a "flake" type of RDF which is typically 3/8-1/2" in size and has a bulk density of about one-half that of coal. This "flake" configuration is formed by compressing the basic RDF substrate. Yet another technique is to add an embrittlement agent to the RDF substrate in a ball mill to form a powder. This method however is very costly and because of the embrittlement agents which have been used in the past adds to the emission problems when

combusted. ANL together with UNT have examined the use of organic acids as embrittlement agents. The research to date seems very promising.

The commercial version of the electric utility power plants that will utilize the b-dRDF technology will consist of existing coal fired traveling grate, spreader stoker boilers and/or existing suspension fired boilers. As shown in Table 5, there were 1,408 units of types in operation by the electric utility industry in 1986, with a capacity rating of 312,245 MW. In 1990, there were 1,455 units, and in 2030 approximately 1,507 units will be on-line with a capacity rating of 357,700 MW.

In estimating the electric utility market potential, we have arbitrarily established a conservative b-dRDF substitution rate of 20% by heat value. That is, the b-dRDF pellets would replace 20% of the coal usage on a Btu basis at the various coal fired electric utility plants that would be used to fire the b-dRDF/coal blended fuel.

The percentage of binder additive present in the b-dRDF pellet was conservatively assumed to be 5% by weight, even though demonstration tests which are currently being conducted may indicate a larger percentage would prove to be optimal. The heating value was chosen at a conservative value of 7,800 Btu/lb. A market penetration of 10% was assumed. This results in an annual lime usage of approximately 1,410,000 tons per year. An average of 122 utility boilers would be retrofitted to co-fire b-dRDF/coal blends during the fifteen year period between 1995-2010.

11 ECONOMIC CONSIDERATIONS

As described in Section 10, the proposed commercial feedstock preparation facility is assumed to have a capacity of 800-1,500 TPD of incoming raw unprocessed MSW. These sizes are compatible with handling the MSW available in assuming a 20% penetration of the total MSW market.

The cost to produce b-dRDF pellets consist of the following cost items: debt service for the capital cost of the facility, operation and maintenance expenses, binder additive costs, and the cost to dispose of the MSW inert residue. Offsetting these costs are the revenue streams consisting of the tipping fee, the recyclable aluminum products, plastic containers (HDPE and PET), ferrous metals, and the fuel pellets. Typically, the tipping fees and the revenue represented by the recyclable products cover the cost items cited above plus allowing for a reasonable profit margin. The fuel pellets represent pure profit which allows some room to negotiate prices to the user.

Table 6 shows the average national tipping fee (the fee that a refuse hauler pays to dispose of municipal solid waste in a landfill). As can be noted, the tipping fee increased drastically in 1988, up 32.3% from 1987. Most observers expect a continuation in the trend toward higher disposal prices -- as landfill regulations become more stringent, and capacity of the existing landfills shrink. Most authorities believe that tipping fees will escalate at rates up to 20% per year for the foreseeable future, at the very minimum. We have conservatively assumed a rate of 12% in Table 5. Even at the conservative rate of 12%, it can be seen that the revenues that will be received

from tipping fees completely overwhelm the other cost or revenue items during the 1990-2010 commercialization time period.

Currently, pellet manufacturers price their product at approximately 20% below the price paid for coal on a dollar per million Btu basis. Assuming that the landfill tipping fee escalates at the predicted rate, it appears that the b-dRDF pellets could be priced at least 30% or 40% of the price of coal with an adequate profit margin for the manufacturer.

Table 7 illustrates the current delivered price of coal and the predicted price of delivered coal from 1990 to 2010. The price of b-dRDF pellets in the same time frame, assuming the pellets are priced at 30% below the predicted coal costs, are shown for comparison purposes.

As far as the economics of the co-firing combustor unit is concerned, a complete economic analysis must be conducted on a site-by-site basis and can include a wide variety of options, fuel types, fuel mixes, characteristics of the combustor, fuel storage, handling requirements, etc. It is not possible to completely quantify the cost; however, some of the details in addition to those normally considered which should be examined for co-firing of b-dRDF pellets with coal include:

- The economic impact of co-firing should be considered from the perspective of the overall operation and economics of the facility as opposed to limiting the analysis to the economics of the power plant.
- The analysis should investigate changes in the fuel expenses, changes in plant boiler efficiency, changes in plant power requirements, changes due to increasing (or decreasing) the peak steam generating capacity of the boilers due to co-firing.
- Within the electric utility industry, determination of the replacement fuel value is very critical to the economic success of co-firing.
- The economics of co-firing may be influenced by ownership of the plant site.

12 CONCLUSIONS

The co-firing of blends of b-dRDF pellets and coal by the electric utility industry represents a very large potential market for the lime industry. Even with the conservative assumptions used in conducting the market analysis, an annual lime usage of over 1,410,000 tons per year was indicated. Other potential markets, albeit much smaller than the electric utility industry include the cement industry, paper industry, agricultural processing, and military installations.

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TABLE 1 Test Schedule

Run No.	Fuel Blend (% by heat content)	Source of dRDF	Binder (% by wt.)
1	Coal	-	0
2	10	TRF	0
	10	MIN	0
3	10	TRF	4
	10	MIN	4
4	10	TRF	8
	10	MIN	8
5	20	TRF	0
	20	MIN	0
6	30	MIN	8
	30	MIN	4
7	20	TRF	4
	20	TRF	4
8	20	TRF	8
9*	30	MIN	0
10*	30	MIN	4
11	30+	MIN	4
12	Coal	-	0

* reduced plastics

TABLE 2 Flue Gas and Ash Samples Collected

● Flue Gas	
- Metals	54
- Inorganic	81
- Organics	94
	<u>229</u>
● Ash	
- Bottom Ash	190
- Fly Ash	176
	<u>336</u>
● Feedstock	
- dRDF Pellets & Coal	26
- Composite Coal/dRDF	35
	<u>61</u>
● Miscellaneous	
- Clinkers, etc.	12
- SDA Feed Slurry	29
- SDA & Baghouse Powders	112
	<u>153</u>
TOTAL	809

TABLE 3 Distribution of Coal Usage By Source

Year	Coal Consumed by U.S. Economy		Coal Consumed by Electric Utilities		Coal Consumed by Residential, Commercial Industrial & Others	
	Tons		Tons		Tons	
	Quads	(10 ⁶)	Quads	(10 ⁶)	Quads	(10 ⁶)
1970	12.3	-	7.2	-	5.1	-
1980	15.4	-	12.1	-	3.3	-
1986	17.3	813	14.5	691	2.8	117
1990	18.8	888	16.1	764	2.7	118
1995	21.9	1034	19.3	912	2.6	114
2000	25.3	1199	22.6	1072	2.7	118
2005	31.1	1467	27.6	1309	3.5	150
2010	36.0	1698	31.4	1485	4.6	191

TABLE 4 U.S. Net Generation of Electricity by Energy Source

Total Generation	2,701,624 GWH	(GIGA Watt Hours)
Coal	1,538,203	(56.9%)
Petroleum	148,819	(5.5%)
Gas	257,779	(9.4%)
Hydroelectric	222,938	(8.3%)
Nuclear	526,901	(19.5%)
Other	11,984	(0.4%)

TABLE 5 Projected Number and MW Capacity of Coal-Fired (Spreader-Stoker and Suspension) Power Plants

Year	Number Of Units	Total MW Capacity
1986	1408	312,245
1990	1455	340,027
2010	1480	348,552
2030	1507	357,702

TABLE 6 Average National Tipping Fees

Year	Landfill (\$/ton)
1984	10.59
1985	11.93
1986	13.43
1987	20.36
1988	26.93
1990*	33.78
2000*	104.49
2010*	324.54

*1990-2010 landfill costs escalated by 12% per year

TABLE 7 Delivered Fuel Prices, in \$/106 Btu

	1984	1990	2000	2010
Industrial Coal	1.6	1.9	2.2	2.4
b-dRDF Pellets	1.28 ¹	1.33 ²	1.76 ²	1.68 ²

¹Assumes pellets are 20% below price of coal.

²Assumes pellets are 30% below price of coal.

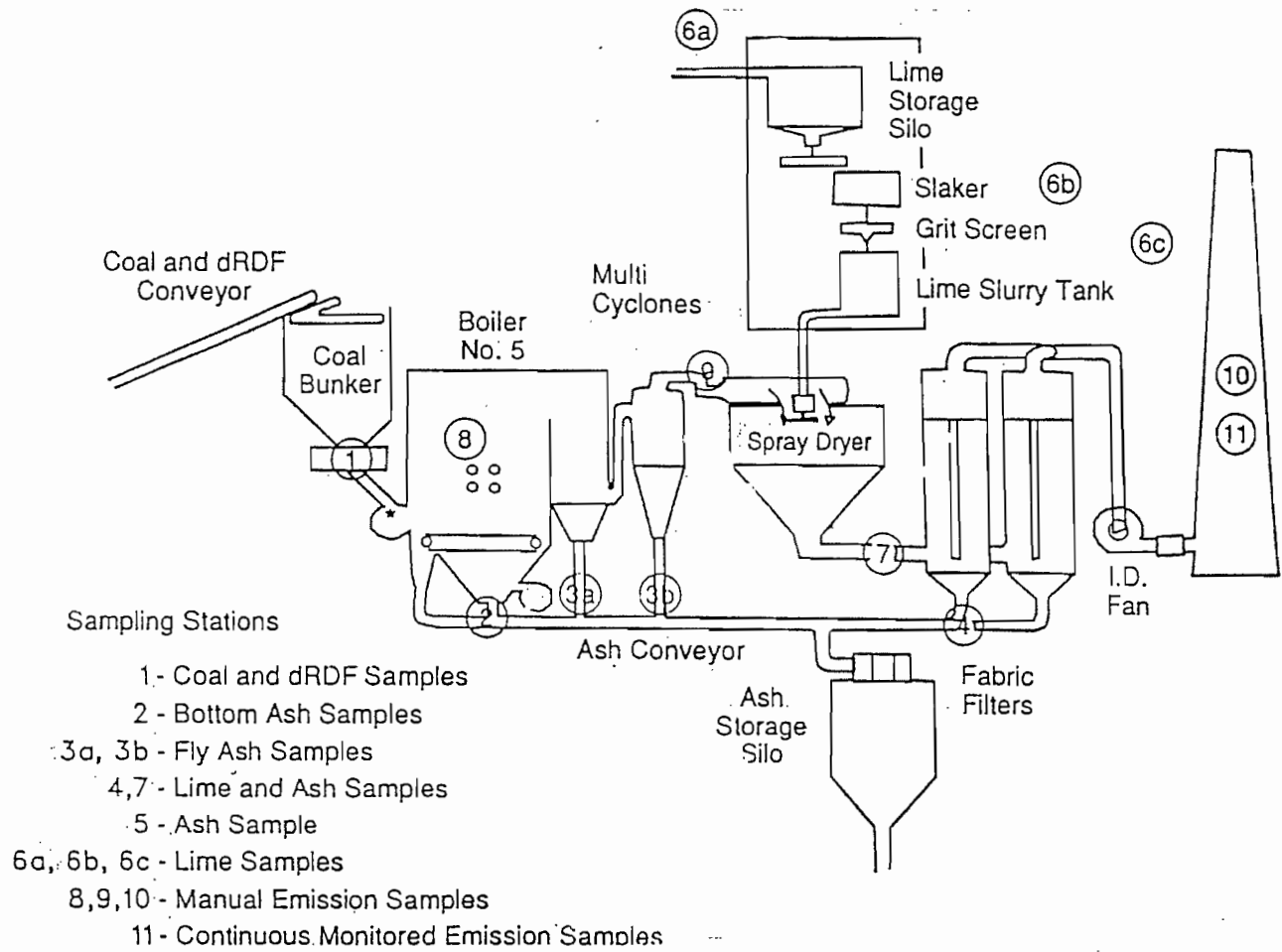


FIGURE 1 Cofiring Test Sampling Station Locations

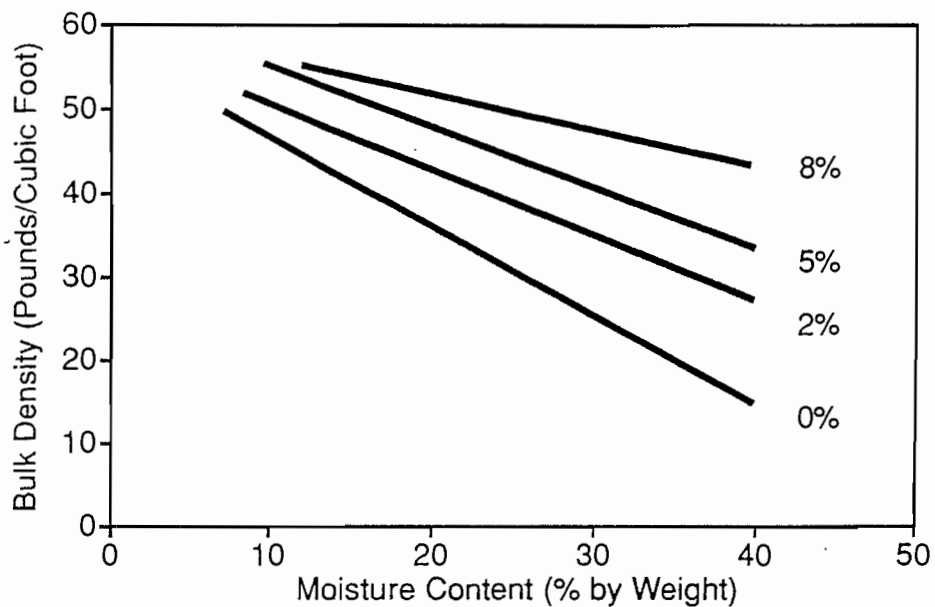


FIGURE 2 Bulk Density as a Function of Moisture Content and Calcium Hydroxide Percentage

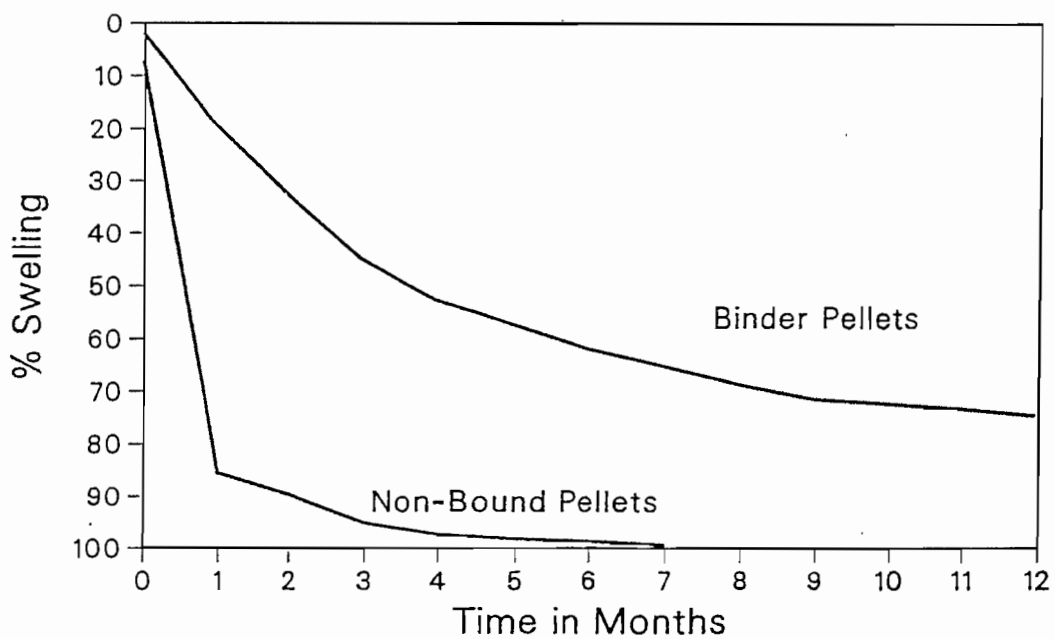


FIGURE 3. Effects of Storage on dRDF Properties (Outside Storage)

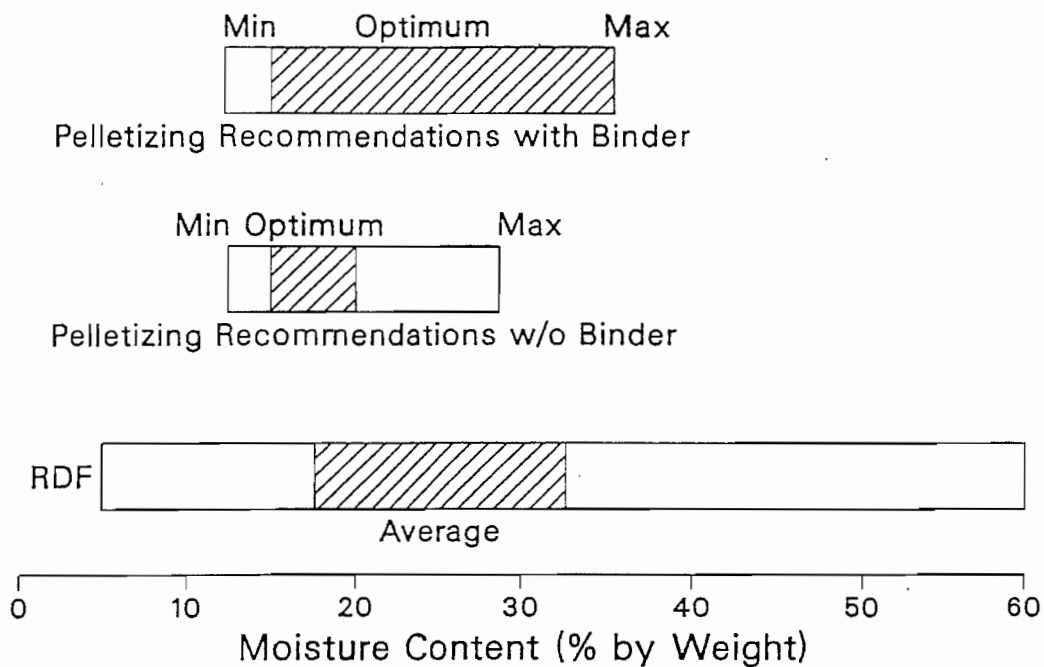


FIGURE 4 Pelletizing Recommendations

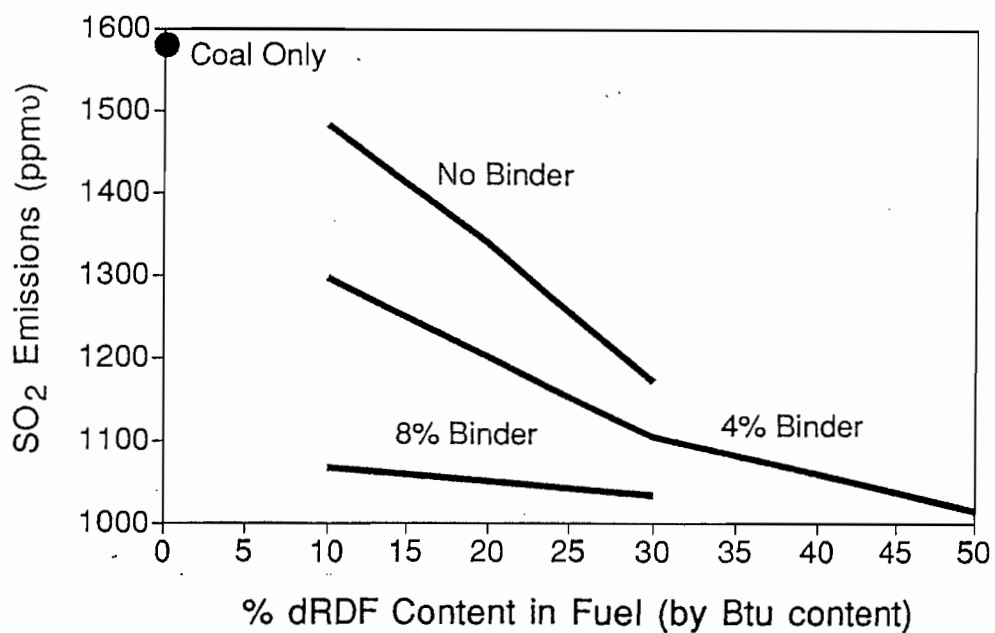


FIGURE 5 SO₂ Emissions (Uncontrolled)

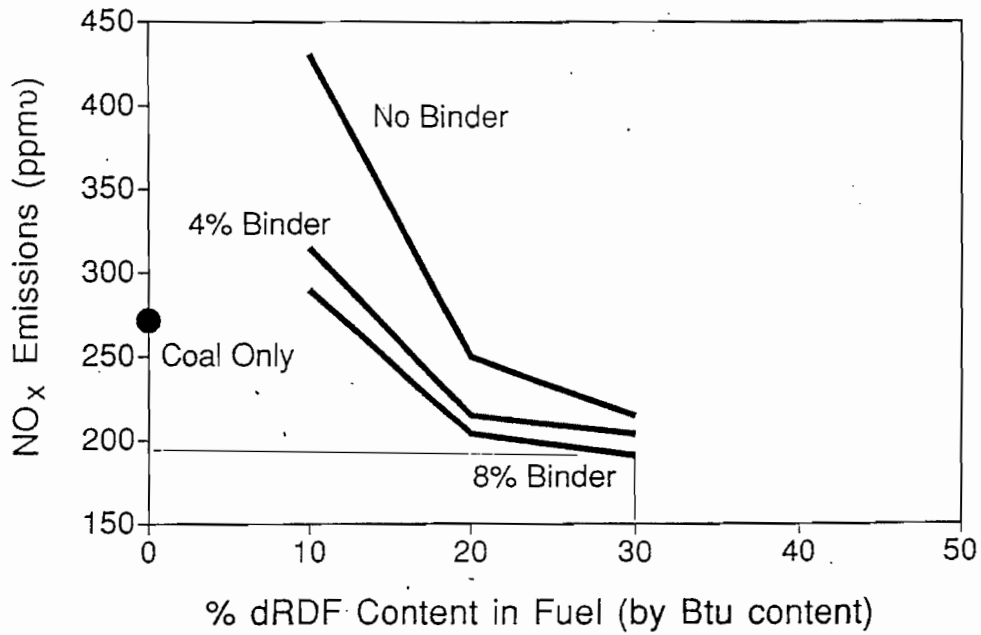


FIGURE 6 NO_x Emissions (Uncontrolled)

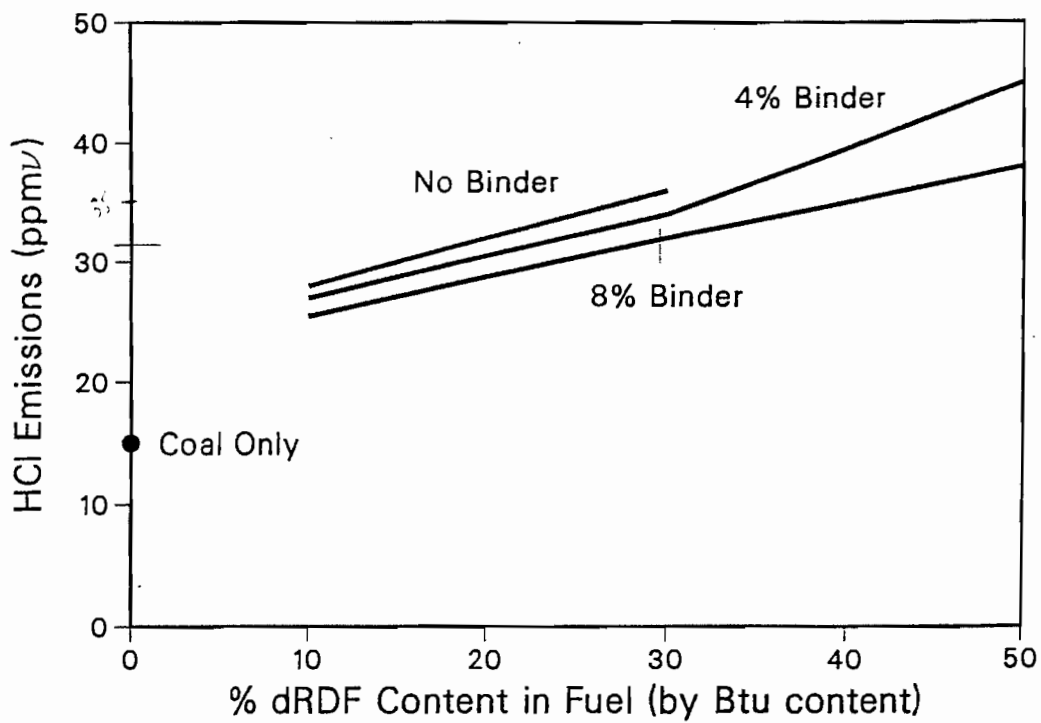


FIGURE 7 HCl Emissions (Uncontrolled)

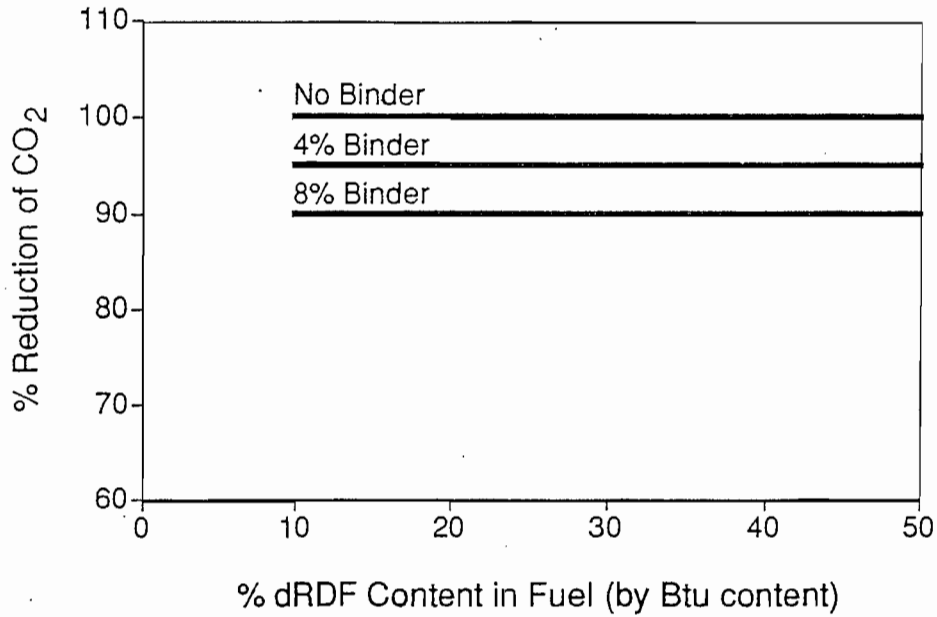


FIGURE 8 CO₂ Emissions

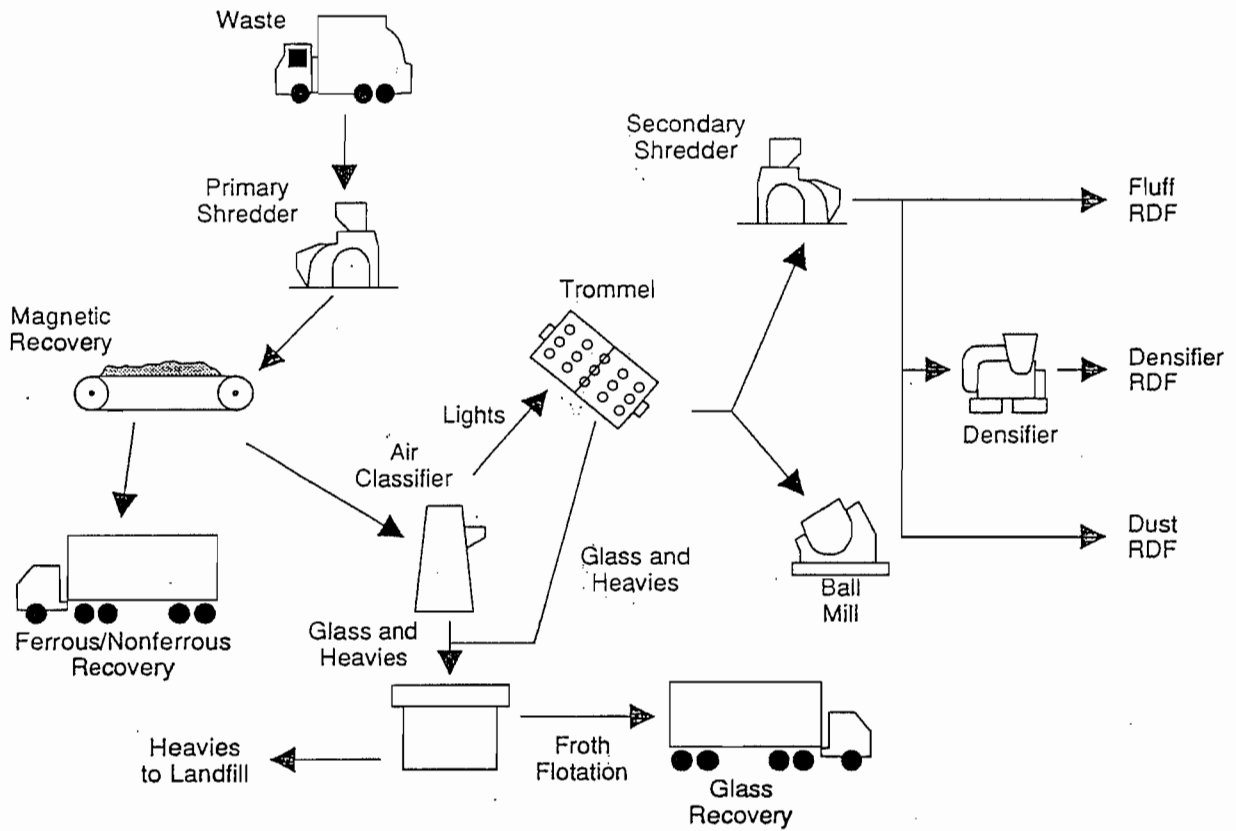


FIGURE 9 Typical RDF Processing Facility

contrast, the untreated soil showed a permeability of approximately 3.5×10^{-6} cm/sec at the start of the testing and the permeabilities ranged from 4×10^{-6} cm/sec to 1×10^{-6} cm/sec after contact with 24 pore volumes of acidic waste. The lime-amended soil not only reduced the amount of liquid passing the test liner (by reducing the permeability) but also reduced the TDS content and the trace metal and radionuclide concentrations in the waste that moved through the liner. The lime-amended liner was considered to be a very successful method for reducing the discharge of pollutants from acid waste piles.

Quicklime mixed with clayey soils has been used to produce hard, impervious soil liners in stock ponds, small earth dams and irrigation channels [7]. In 1972, a large-scale canal lining project was undertaken using quicklime-amended soil. Quicklime was mixed with the heavy clayey soil (using 4% CaO) and compacted on the bottom and sides of the canal. The trial consisted of treating a 3.3 km stretch of canal. The compacted, quicklime-treated earth has proved to be a strong, impermeable liner. No major leakage or slope failure has been noted although the canal section holds 5.7 meters of water for approximately 10 months every year.

Lime-fly ash - aggregate liners have also been successfully employed in building reservoirs for clean water storage. Typically a 15-to 30-cm thick layer of lime, fly ash, and gravel is mixed in place and compacted. The lime and fly ash undergo a pozzolanic reaction and the resulting concrete typically has much greater compressive strength than lime-soil liners.

A compacted hydrated lime liner was constructed by BASF Corp. for a hazardous waste landfill on the island of Flotzgrun near Speyer, Germany [8]. The ground surface was built up above the water table and a 50-cm thick layer of lime is used under most of the wastes. The industrial waste are carefully selected to include a high proportion of inorganic materials. Ground water is kept out of the wastes and any discharge from the waste must pass down into the lime liner where any acid is neutralized and heavy metals are precipitated and retained.

Lime in Landfilled Wastes - Lime is often used in water treatment to precipitate potentially toxic metals and neutralize acid [2]. Lime application for metal precipitation requires adjusting the pH to produce the lowest solubility. Most potentially toxic metals (such as cadmium, chromium lead and nickel) are amphoteric; that is the metal hydroxides show increased solubility at very

low and very high pH's. Figure 2 shows the variation in solubility with pH and typical pH ranges achieved during lime neutralization. Direct lime addition to waste can be helpful in maintaining a metal hydroxide waste in an pH range that results in low hydroxide solubility.

Crawley, Brown and Anderson [10] outlined techniques for using hydrated, high-calcium lime to treat acidic sludges and produce acceptable sludges for landfilling. Remedial action using hydrated lime injection proved very effective in halting ground-water pollution under and around acid waste pits. Sludge neutralization with lime was undertaken to allow the closure of two acid disposal pits and landfilling of sludges from the neutralization. Calcium hydroxide slurry was pumped directly into the impounded acid wastes and mixed using aerators. The pH of the waste was brought up to 6.7.

After the lime pits were backfilled and covered, cores of the soil below the waste were obtained. The subwaste soil had pH's as low as 4.0. High-pressure, lime slurry injection in closely spaced holes (1.6 meters apart) was used to neutralize acid-contaminated soils beneath the closed pit.

Conventional (non-hazardous) industrial wastes have also been treated by adding lime or by-products containing lime. Morgan, Novoa and Half [11] developed and tested a variety of lime and by-product mixes to use in treating an oil refinery sludge. The final treatment system consisted of mixing stale and fresh cement kiln dust in a ratio of 3-to-1 with oil sludge. The mixed sludges produced a moldable solid that hardened to produce a strong landfill material.

Techniques for blending lime, fly ash and waste to produce a hard pozzolanic, cemented hazardous waste for landfill have been summarized by Colussi and Mullen [12]. Pozzolan concrete-waste blends have been produced that have sufficient strength to support the fill and provide good slope stability. In a structural fill, treated waste was placed on high ground at least 1.6 meters above the water table. The lime-fly ash, treated wastes are placed in 0.6 meter lifts and compacted to produce a cemented layer with an unconfined compressive strength of cover comparable to soil cement and a permeability less than or equal to 1×10^{-5} cm/sec. Each layer of the fill is an alkaline-buffered, low-permeability pozzolan concrete. A structural landfill is made up of multiple cap-like layers of pozzolan concrete. All slopes are covered and vegetated to further reduce contact of the waste with water.

Fly ash-lime pozzolans have also been employed in solving problems related to settlement and gas production in landfills containing municipal refuse. Blacklock, Joshi and Wright [13, 14] described a technique for injecting a lime-fly ash grout into landfills containing municipal refuse. The grout is injected until refusal using pressures up to 689 Pa (100 psi). Holes were spaced on 3 meter (10 ft) centers and grout was injected to the bottom of the fill. The grout spread out and hardened into web-like masses that segregated masses of the refuse. The landfill material was strengthened and the release of methane at the landfill surface was almost entirely eliminated.

Lime Addition to Landfill Covers - In cases where it is not practical to directly inject lime into a landfill the acidity of water entering the fill can be controlled by adding lime or blends of lime-based material to the cap. Francis [15] reported an interesting application of lime and limestone to a landfill cap to maintain alkaline conditions inside an industrial waste landfill. A mixture of crushed oyster shell (calcium carbonate) and hydrated lime was added to a cap placed above a hazardous waste landfill that contained metal hydroxide wastes. The lime-limestone cap provided assurance that all the precipitation infiltrating the waste had been raised to a pH that would not cause solution and transport of potentially toxic metals.

Summary - Lime and products containing lime can be incorporated to advantage in all major components (liners, wastes and caps) in both hazardous and conventional landfills. Lime can control pH of infiltrating or exiting water and can provide a chemical barrier to toxic metal transport. Lime-pozzolan reactions can be used to provide structural stability in waste and prevent waste consolidation and disruption of the landfill cap. Lime can also be used to control biological activity in fill by controlling the pH and the availability of critical nutrients.

A program involving carefully monitored full-scale demonstration projects with lime are needed to prove the environmental acceptability of lime augmented landfills and develop criteria for routine landfill designs with lime. Where waste material containing lime (or pozzolan) are employed guidelines should be developed as to the chemical characteristics that are needed for the waste to be used in landfill design.

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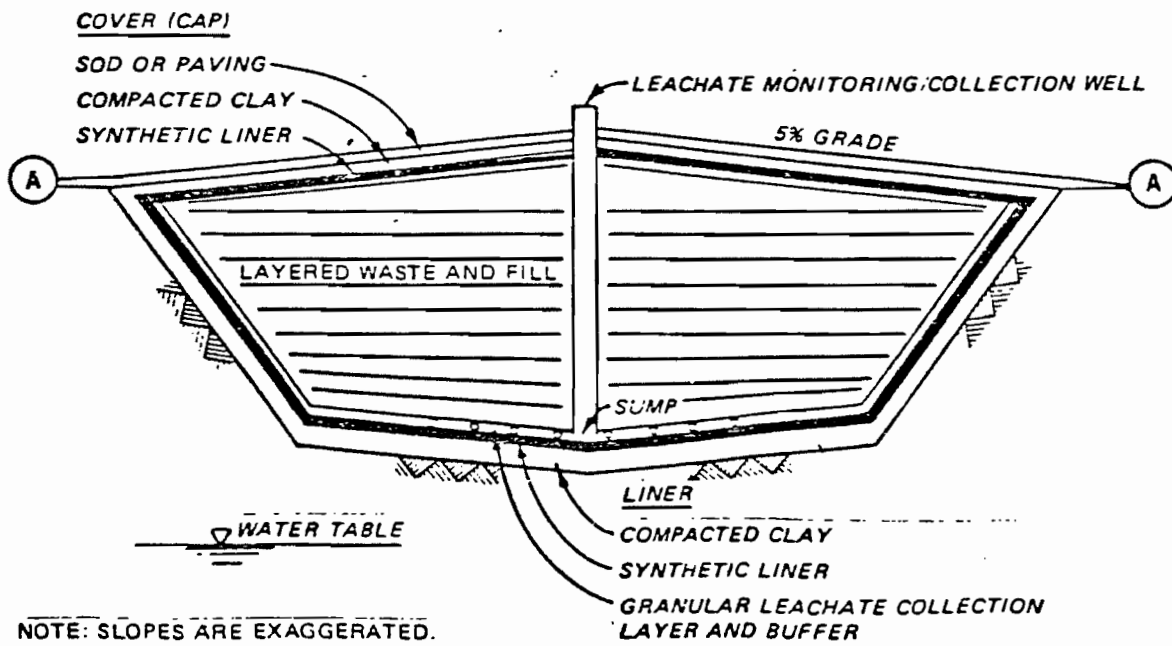
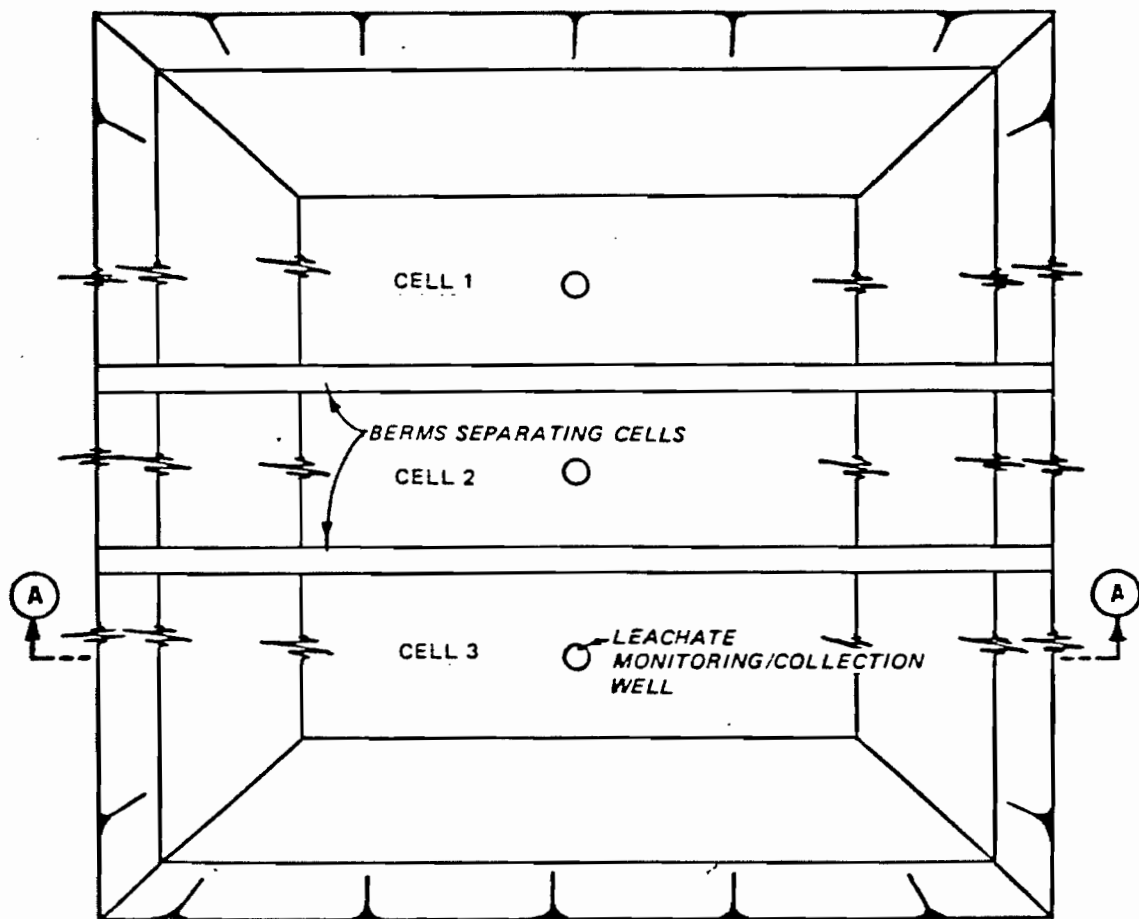
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NOTE: SLOPES ARE EXAGGERATED.

Fig. 1. Diagram of a generalized landfill design showing cover, waste and liner.

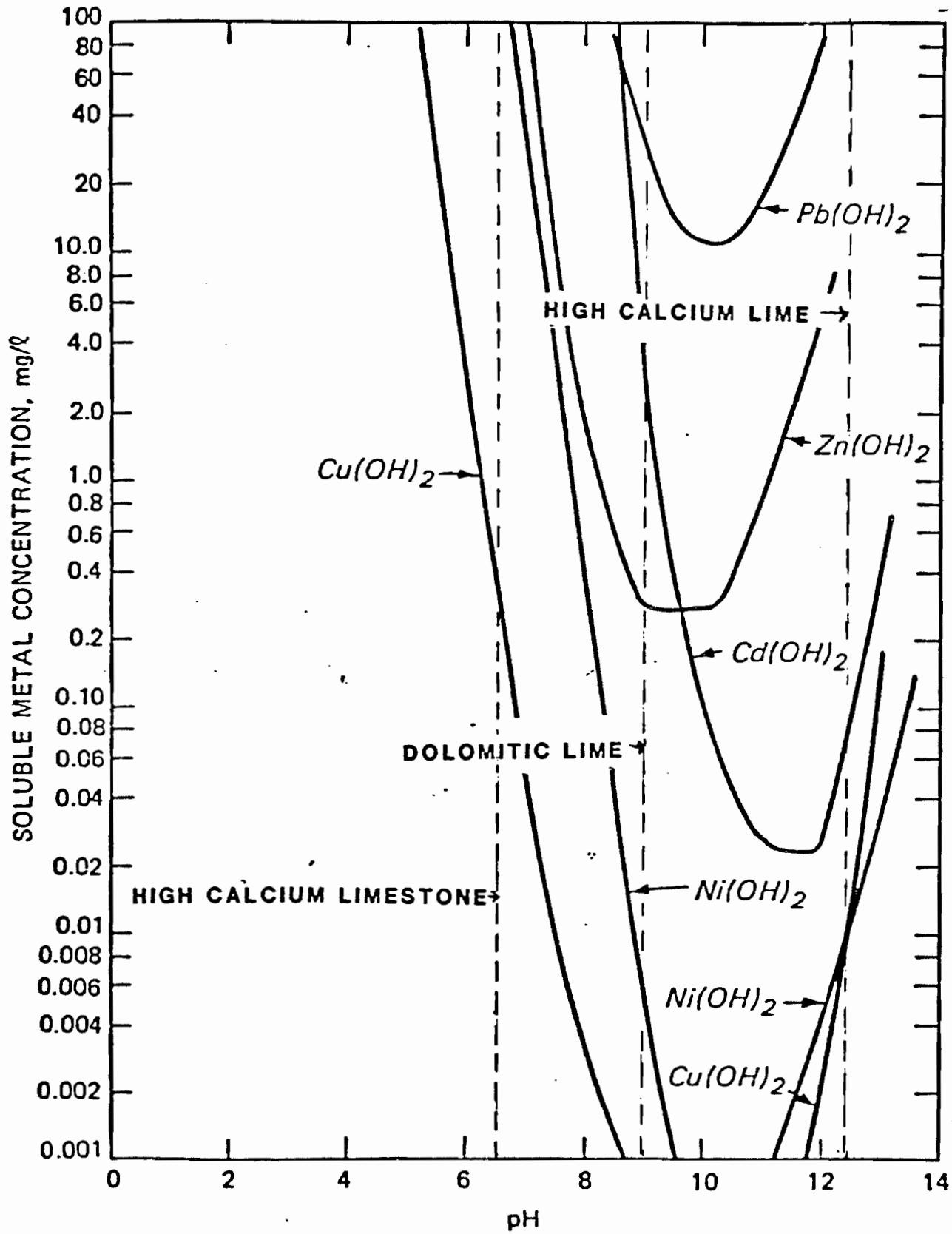


Fig. 2. Variation of theoretical solubilities for metal hydroxides with pH. The dotted lines mark the pH levels obtained with limestone, dolomitic lime and high calcium lime. Data are from references (2) and (9).