Conf-900407--11

WSRC-RP-89-1174

ADVANCED RADIOACTIVE WASTE-GLASS MELTERS (U)

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WSRC-RP--89-1174

DE92 017926

Author's signiture

For presentation at the American Ceramic Society annual meeting
Dallas TX,
April 22, 1990

Authorized Derivitive Classifier

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Advanced Radioactive Waste-Glass Melters (U)

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SUMMARY

During pilot scale operations of the Scale Glass Melter for the U.S. Department of Energy a team of engineers and scientists was formed to assess the need for continued melter design development to support the Defense Waste Processing Facility (DWPF), and prioritize future efforts. Recently this has taken on new importance because of selection of the DWPF Melter design as the reference for the Hanford Waste Vitrification Project (HWVP), and increased interest at the West Valley Demonstration Project on melter life and replacement. Results of the study are summarized, and goals produced by the study are compared to the results of current programs at the Savannah River Laboratory (SRL).

Slurry fed melter development and waste glass composition models and controls were developed for the conversion of High Level Radioactive Wastes that are water soluble or dispersible slurry. However, U.S. Department of Energy facilities also contain other types of radioactive and hazardous wastes which have relatively low penetrating radiation levels. Thus, this paper also considers how the technology developed for High Level Wastes might be applied to the immobilization, volume reduction and stabilization of Transuranic (TRU), Pu^{238}, uranium (beta/gamma), and chemical (RCRA) wastes, as well as mixed radioactive/chemical wastes (mixed wastes). Wastes of these types generally do not require heavy shielding to control radiation doses to operating and maintenance personnel, permitting direct maintenance. However, these wastes share many contamination and environmental release concerns with High Level Waste. Thus, it can be expected that treatment of these wastes is possible by adapting technology developed for the treatment of High Level Waste.

Using criteria selected for the Advanced Melter Program a new class of waste glass melters has been designed, constructed, and proof-of-concept tests completed on simulated High Level Radioactive Waste slurry. The resulting 1 foot square agitated melter is full scale for transuranic and Pu^{238} wastes, and approximately 40% linear scale for DWPF operations. Melt rates have exceeded 32 pounds per hour glass with slurry feeds, and 47 pounds per hour with dry feeds. This is an 8 fold increase in the melt rate possible in similarly sized melters of older designs and essentially duplicates in a glove box-sized unit the throughput of the large, remotely-operated French AVH systems. Melter power was not limiting and further

increases in melt rate are expected by optimizing the agitation and dispersion of slurry. The resulting glass is uniform, with high durability, and essentially void free.

Melt rates in this new class of waste glass melters may be proportional to melter volume instead of surface area. It is therefore projected that a melter with a 2.5 ft square surface could replace the 6 foot diameter DWPF or HWVP production melters. In its currently unoptimized form it is expected that a 2 ft square melter of this design is large enough to meet melt rates required by the West Valley Demonstration Project (WVDP).

This new melter design combines the high production rate of large ceramic lined melters with the low cost, simplified construction, and simplified disposal of pot melters. Equally important, the melter can be designed as a modular system, such that only failed components need be replaced to return the system to operation. Scale up of the design,and development mechanical details to seal the melter are being considered for development of a generic melter. The necessary supporting facilities (incineration, feed preparation, offgas scrubbing) have been demonstrated as parts of other programs.

INTRODUCTION

Slurry Fed Melters (SFM) have been developed in the US, Europe and Japan for the conversion of high-level radioactive waste to borosilicate glass for permanent disposal [1-6]. Laboratory and pilot scale operations have been conducted to develop equipment, glass compositions and control methods. Figure 1 illustrates the types of melter systems that have been developed. The melters fall into three general classes; batch melters, continuous pot melters, and Joule-heated ceramic-lined melters.

The first waste glass melters were designed for batch operations, a direct increase in scale from crucible tests. This approach was found unsuitable for production facilities because of slow melt rates caused by slow heat transfer from the external heaters through the canister into the reacting batch. Lack of agitation and temperature nonuniformities made it difficult to homogenize the glass. Calcination of feed before introduction into the canister increased the melt rate but also increased the tendency for crystal formation in the glass, and entrained waste in the calciner offgas system. This method was finally eliminated based on the large number of melters, operating in parallel, required to meet the production rates required to dispose of HLW inventories.

The second class of melters developed were continuous pot melters. In this type the melt rate was increased by increasing the diameter of the pot, by direct heating of the pot by radio frequency induction heating, and by continuous feeding of raw materials. Glass homogeneity was improved by using gas bubblers to agitate the melt. The largest of this type of melter is the French AVH system which melts 55 pounds per hour. This is the processing rate limit per pot melter using dried feed: With slurry feeding the melter capacity limit would be about one half of this, or 27 pph per melter. The melter design temperature is limited to about 1050°C by creep resistance of the Inconel (TM) alloy used for the pot. The use of this system was not practical in the DWPF because of the large number of parallel melters, calciners and offgas scrubbing systems required. However, this class of melter is modularized, with parts that are relatively easy to replace. An additional benefit of this approach is that only the failed components need be replaced, minimizing the amount of waste generated with melter changeout, and maximizing the useful life of each component.

The third category of melters are the joule-heated ceramic-lined melters. In this type the melter is lined with refractory, and the glass is directly heated by conducting electricity through the melt. This system with slurry feeding has been selected for all the production melter systems in the US, W. Germany and Japan because of high production rate and high glass quality. The size of these systems is effectively limited only by operating facility constraints (e.g. cell space, crane capacity) since all the structural support is provided by a room temperature metal box which contains the refractory. The Inconel 690 (TM) alloy electrodes only need to be self supporting, and high current densities are possible on the faces of the electrodes [7]. Therefore nominal melt temperatures can be as high as 1150°C, which is only 200°C lower than the melting point [8]. Glass production rates are proportional to the surface area of the melt, but convection caused by the joule heating is enhanced as the size of the melter is increased, so larger melters have proportionately higher melt rates. Small laboratory melters operate below 4.5 pounds per hour per square foot, production melters operate at about 8 pounds per hour per square foot. Melt rates can be doubled by dry feeding. The combination of higher temperature and convective mixing makes the glass very homogeneous.

The major difficulty in slurry-fed ceramic-lined designs is the large number of individual refractory bricks, supporting shell and other components that are required to be assembled to make this type of melter. This complexity increases the melter construction, installation and disposal costs. In radioactive service only limited repair is possible, so failure of individual components can require removal and disposal of the entire assembly.

DISCUSSION

Design Objectives for High Level Radioactive Waste Disposal

The Defense Waste Processing Facility (DWPF) being constructed at the U.S. Department of Energy's Savannah River Site has an anticipated operating life of over 16 years, using a replaceable melter with a design life of 2 years. Following the operation of pilot scale melters (Project #1941, Large Slurry Fed, and Scale Glass

Melters) the Savannah River Site formed an Advanced Melter Program Task Team to evaluate incentives and alternatives for the continued design, construction and operation of experimental melters. The Team used experience acquired during design, construction and operation of the pilot scale melters, and economic models developed to estimate operating costs of the completed DWPF.

Probabilistic decision analysis techniques were used to evaluate the questions of whether or not an "Advanced" melter program should be undertaken, and what the expected value would be, strictly based upon inside DWPF operating costs. The first four DWPF melters were assumed to be of the current design, and all succeeding melters of an advanced design, except for a baseline case with the current design maintained. Melter variables included life, cost, and performance. Other uncertainties that were evaluated included total DWPF throughput and total annual operating cost.

Advanced HLW Melter Design Concepts: Three advanced melter concepts were evaluated: an "improved" or optimized version of the current design, a very long-lived and somewhat more expensive "modular" melter, and an inexpensive but short lived "disposable" melter:

The Improved melter uses the basic initial design but makes gradual improvements. This is the normal glass industry practice, with generally good results (e.g. a 2 fold increase in melter life might be expected).

The Modular melter strives for a long melter life by significant improvements in design, materials, and remote maintainability. The latter feature might be envisioned as the ability to remotely replace all vital component modules; hence, the term "modular" melter has been used. Such a melter may be approached by evolution of the current design, but some revolutionary design changes may be needed.

The Disposable melter strives for low melter cost, and perhaps low melter disposal cost. Such a melter may use a metal tank, like the French AVM/AVH systems [6], and has been termed "disposable".

On an economic basis, any Advanced Melter program for a facility with operating requirements similar to those of the DWPF should focus more on performance than on melter life or cost. In the decision model four alternatives were evaluated: Base, Improved Base, Modular, and Disposable. The Base case assumed no evolutionary improvement. Rather, it is merely a no-change baseline for comparison. The expected DWPF inside cost saving over that of the Base case is about $100 million for any of the three Advanced Melter concepts. Most of the cost saving in all three cases is due to enhanced melter performance (throughput), resulting in reduced operating cost. For the three cases- Improved, Modular, and Disposable - melter performance accounted for 93%, 86%, and 90% of the cost savings, respectively. This result was not anticipated as evidenced by the fact that the Modular and Disposable cases were set up to emphasize melter life and cost, which proved to be relatively unimportant.

Economic incentives not included in the decision analysis above are 1) reduction of onsite operating and offsite disposal costs by increased waste loading, 2) income from recovery of usable products in the waste, 3) reduction of outage time if the current melter design does not meet expectations of production rate or operating life, and 4) reducing ultimate melter decommissioning/disposal costs by reducing the number of melters or designing them for ease of decontamination and disposal. Separate analyses of these factors have been conducted for all except decommissioning using models discussed earlier [9-11].

Maximum melter reliability, ability to operate at high rates to recover lost production time, and increased waste loading should be Advanced Melter goals. A separate analysis of melter economics was made using an economic model of the expected cost of DWPF operations [9]. It is helpful in understanding the impact of melter performance. A baseline of 75% utilization was used, comparable to the the DWPF design objective for overall attainment. In this analysis costs are proportional to the length of time required to convert the existing SRS High Level radioactive waste. Cost savings can then be achieved by either decreasing the frequency and length of equipment outages, or by increasing the instantaneous production rate. Table 1 summarizes the costs savings, regardless of the source of this increase in productivity. Higher than 100% utilization is theoretically possible since the utilization is based on the design reference rate of glass production. Since disposal of waste is the ultimate goal, rather than production of a good for sale, the utilization can also be increased by increasing the concentration of waste in the glass product. For example, 100% utilization might be achieved by increasing the instantaneous production rate to 125% of the design basis rate, with the facility producing glass 80% of the time, or by a proportional increase in the waste loading. Conversely, if the existing melter design does not meet expectations, then the time for vitrification of existing waste will increase, and operating expenses prolonged because of lower productivity. Increased instantaneous melt rates are particularly attractive, since they may be used to return to weekly production goals, even if sustained outages are incurred. Increased waste loading not only increases utilization, it also reduces the amount of repository space required for waste disposal, which has higher potential cost savings than any of the other goals considered.

The Task Team evaluated all the above analyses and ranked the melter objectives in order of priority. See Table 2, which summarizes the results. Subsequent melter development and demonstration work has concentrated on characterizing and optimizing the existing design.

Application of HLW Technology to Other Waste Types

The scope of the Advanced Melter Program Task Team was restricted to evaluation of the economic impact on the DWPF of advanced melter development. However, U.S. Department of Energy facilities also contain non-High Level Wastes which have relatively low penetrating radiation levels. It is important to make the best use of the available technology developed for High Level Radioactive waste to aid in the safe and efficient disposal of these wastes. Therefore, this paper considers for the first time how the glass technology developed for High Level Wastes might be applied to the immobilization, volume reduction and stabilization of Transuranic (TRU), Pu^{238} (alpha), uranium, beta/gamma, and chemical (RCRA) wastes, as well as mixed radioactive/chemical wastes (mixed wastes). Wastes of these types generally do not require heavy shielding to control radiation doses to operating and maintenance personnel, permitting direct (hands on) maintenance. However, these wastes share many contamination and environmental release concerns with High Level Waste. Thus, it can be expected that they would require similar waste-form quality, and production control practices as the High-Level Wastes, but the scale of operations, and equipment design would differ.

Potential benefits of the application of the existing waste glass technology to the disposal of other waste types include: well characterized waste form stability and extremely low release rates in a variety of environmental conditions, excellent mechanical and thermal stability, no combustible or pyrophoric properties, retention of essential release properties even if disturbed or mechanically damaged during storage or disposal, low generation of potentially respirable particles, the ability to accept high loadings of heavy metals, ability to accomodate fluctuating waste types with negligable effect on release properties, ability to combust limited amounts of organics (including carcinogens), total destruction of asbestos, and scale of facility adaptable to accommodate a wide range of disposal needs.

An important indication of the waste retention capabilities of waste glass is a dimensional analysis of the respective waste leach tests used for radioactive waste glass, commercial glass, and hazardous wastes[12]. It can be inferred from this analysis that typical waste glass has a durability 1,000 to 100,000 times more durable than that required for the derating of hazardous chemical wastes: Typical waste glass durabilities are comparable to granite, basalt and other durable rocks [13]. Thus, it is practical to consider the construction of a facility for converting certain mixed chemical/radioactive wastes into stable radioactive waste forms that do not exceed RCRA criteria. This could have significant impact on the cost of disposing of such wastes, and could also minimize radiation doses that are expected because of certain surveillance procedures necessary for the storage of mixed wastes that would not be necessary for wastes derated to low level radioactive waste.

The characteristics of waste-glasses and processes required to effectively process and dispose of hazardous wastes are summarized in Figure 2. Characteristics of the waste form and the processing equipment are rated in importance for the various waste types, with small dots indicating items of minor importance and large dots indicating major requirements. Blank spaces indicate relatively unimportant characteristics.

As is evident from Figure 2, the High Level Waste disposal programs have gone a long way in addressing the concerns for the other waste types. In many ways High Level Waste disposal is the most difficult, since it combines the requirement of very durable and stable waste forms with remotely maintained equipment. The other waste types require various levels of contamination control, but none would require large remotely maintained facilities. Thus, the waste glass formulations developed for HLW should be applicable, as well as the materials of construction, but the lack of need for remote maintenance should permit more flexibility in the design and construction of the various melters and related equipment.

Other Waste Types

β–γ wastes are generally disposed of in cement waste forms, or deep burial of

stabilized waste, because their hazards are similar to those of the uranium ore these wastes originally came from. However, if the wastes are contaminated with hazardous chemicals, α isotopes, or have unusually high activities the added

stability and leach resistance of vitreous waste forms may be required. It is probable that such a disposal method could be made practical by minimizing the cost of the melter and the raw materials fed to the melter, making it economically comparable to cement based waste forms. This should be possible through the use of standardized melter designs, and mineral based raw materials, much as the commercial glass industry. Economics may be of less concern when the final disposal site is near population centers or regional water supplies, where improved durability would aid in acceptance of the disposal method.

Mixed wastes, heavy metals, inorganics, asbestos, and organic wastes share many of the characteristics of β–γ wastes, but they contain listed chemical elements or

compounds which require permanent isolation from the environment. The high temperature melting process destroys the chemical compounds associated with such wastes, and ties poisonous elements up into a durable matrix. It is believed that with controlled chemistry the final waste form would meet health based limits for shallow ground disposal of such wastes. Again, economics plays a major role in the effective disposal of these wastes, and the ability to obtain generic licensing of the waste form and the process would be very desireable. With generic licensing it is possible to imagine a "melter on a truck" which could be moved between disposal sites, converting commercial wastes on a fee basis. A small melter offgas scrubber system has been installed on a trailer to make it transportable, and is being used in incinerator studies. Such a design could be used in support of a portable design to vitrify miscellaneous wastes.

α **wastes, (TRU) wastes** are comparable to High Level Waste in biologic risk, but require small scale operations. Generally Pu^{238} and Pu^{241} are considered separately from other transuranic isotopes [14]. For this discussion Pu^{238}, and Pu^{241} will be categorized as α wastes, and all other transuranics as TRU wastes. In these waste types major goals are to convert small volume, low activity and often flammable wastes into small waste forms that are easy to handle, but provide a high degree of contamination control (isolation). Waste glass is essentially a sealed source, which will reduce the dispersibility of α wastes during accidents, and transfers negligable activity by contact. The high temperature melting process combusts organics, and reduces the volume of this waste catagory, which primarily consists of contaminated plastic, cloth and paper products. HLW laboratory melters are full scale demonstrations for these waste types. Waste loading is expected to be controlled by the solubility of fluoride and chloride in the glass. An early use might be for the disposal of α incinerator ash.

Diasarmament If the nation's inventory of nuclear weapons is to be permanently reduced, then a means of denaturing and disposing of the weapons grade materials (Pu^{239} and Enriched U) must be found. Enriched uranium can be blended down with lower enrichment uranium and used for power generation. However, the US does not have a breeder reactor capable of comparable use of plutonium for fuel. One possible means of controlling these materials is to vitrify in a glass containing neutron poisons. Such a waste form would permit high Pu and U concentrations, permitting inventory and verification by calorimetry or radiochemical methods. Pu in such waste forms could be recoverted, but conversion would be slow and difficult making it unlikely that arms control agreements would be violated by reprocessing such materials. In this application nuclear criticality control and materials accountability would be major requirements, so a very small melter that is well mixed and totally drained between batches would be appropriate.

SRL ACTIVITIFS RELATED TO ADVANCED MELTER DEVELOPMENT

Improved Melter Design

The majority of the current programs are in support of the operation of the DWPF with the existing melter de.ign, with possible evolutionary design changes. However, these programs provide much of the necessary basis for the development of Advanced Melters. In most cases this is to provide contingency planning to assure that melter design objectives of throughput and melter life can be met. The major uncertainty in the life of DWPF and Hanford Waste Vitrification Plant melters is the possible accumulation of insoluble materials on the melter floor. In the case of the DWPF these are most likely to be electrically conductive alloys of the fission products Ru, Rh,Pd, Ag, Te, and Se. In the case of the HWVP these could also be ZrO_2, or Cr_2O_3. Another paper focuses on possible modifications of the DWPF process or equipment to minimize the risk associated with the noble metals [15].

One of the most influential of the programs in support of the existing design was the recently completed **Scale Melter Drain and Restart Program**. The program demonstrated that the method of keying bricks into the DWPF melter is effective in preventing significant damage to the refractories during programmed drainage, cool down and restart. This makes possible the serious consideration of draining a damaged melter, moving it to a repair facility, repairing it and reusing it. Conceptual designs have been developed for replacement of the riser/pour spout and bottom drain assemblies [16]. Demonstrations of remote water and abrasive blasting techniques also make it possible to consider recovery from electrical shorting on the melter bottom caused by accumulations of noble metals or other conductive species [17].

Melter tests and physical chemistry studies are being conducted to determine how feed preparation influences the potential for noble metals accumulation, primarily by determining what influences the particle size distribution of noble metals. Physical modeling of the electrical effects of noble metal accumulation is complete [7], and finite element modeling is being developed to predict where and how rapidly the noble metals might accumulate. These findings and methods are adaptable to a variety of potential melter designs.

Polycrystalline chromium electrodes have been fabricated and tested in a small laboratory melter, as a means of increasing melter operating temperatures and waste loadings [18]. The chromium was satisfactory, but is attacked at the air/glass interface, much as molybdenum is attacked in commercial melters. Thus, it should be possible to fabricate waste glass melters with a higher operating temperature, and the economically desired increase in waste loading, but not using the present DWPF design. Fabrication of a laboratory melter with totally submerged electrodes and thermowells is being considered as a low priority program.

DEVELOPMENT AND DEMONSTRATION OF AN ADVANCED MELTER

Melt reaction studies, computerized staged reaction models, organic combustion models and melter redox models are being developed to support the DWPF melter. Evaluation of the melt reaction sequence indicated that the melter operating temperature need not be as high as the nominal 1150°C to assure adequate glass durability [19,20]. This made possible the consideration of melter designs where Inconel 690 components carry dynamic loads, which is not possible with the present nominal operating temperature of 1150°C.

Several melter design companies were consulted to determine what commercial technology might be applicable. The most promising of these was a proposal by Associated Technical Consultants to develop mechanically stirred melters comparable to those originally investigated by Owens-Illinois Co. [21]. This approach offered the possibility of combining the size of the continuous pot melters with the high production rates of Slurry Fed Melters: O-I demonstrated a compact 2 ft cube melt chamber that produced 24,000 pounds per day of partially melted commerical glass from raw materials. It features a simple geometry, with a simple mechanical drive system, and rapid start, drain and restart capabilities, all of which are desirable properties for radioactive service.

The existing O-I design did not meet the requirements of HLW disposal because it:

1) required natural gas combustion to start
2) was constructed with electrode and agitator materials chemically incompatible with waste glass feeds
3) produced partially-reacted foam rather than fully-reacted, dense glass
4) could not guarantee that unreacted batch would not be delivered with the final product
5) had restricted electrode surface area
6) used refractory lining, sharing scale up, glass sealing and disposal concerns with the existing ceramic-lined melters

A major uncertainty in attempting to apply stirring technology to waste vitrification was the effect of stability of slurry feeding on the melting process. Instabilities might cause an uncontrolled amount of entrainment in the offgas system, result in glass freezing on the agitator, or have uncontrolled flow from the output spout.

It was determined that necessary characteristics of a practicable agitated waste-glass melter are:

1) adequate durability of glass product
2) all electrical heating
3) use of electrode and agitator materials compatible with oxidizing melts
4) use of alloys with known creep characteristics for predictable melter life
5) maintenance of temperatures and stresses below creep rupture conditions
6) elimination of porosity in product glass
7) stable glass flow with slurry feeding of raw materials
8) self sufficient startup power from resistance heaters
9) vapor space resistance heaters available for melt rate stabilization
10) vapor space temperature above 600°C to combust organics
11) ability to drain the tank
12) predictable melter life greater than 6 months.

To minimize glass sealing concerns, and scale up, disposal and repair costs, it is desirable to have all glass contact materials out of one metal alloy rather than a mixture of alloys and refractories. Based on high chromium alloys corrosion studies [18], waste melter operating experience, and limited creep rupture and creep strength data [23], it was therefore specified that all glass contact materials be constructed of Inconel 690 (TM) with a maximum operating temperature of 1075°C.

It was determined that for a first attempt at slurry feeding a stirred melter, the melter should have about 1 square foot of melt surface. This is a typical size for laboratory waste melters, but is about the largest size that can be easily installed and maintained in a glove box, and is therefore production scale for glove box waste disposal. With increased melt rates a 1 ft^2 melter can be considered a pilot scale melter, comparable to the Scale Glass Melter for facilities such as the DWPF.

A melter was designed and constructed to these criteria, and tested with simulated HLW slurry [20,22]. To minimize costs the melter did not attempt to include mechanical design details required to seal the melter for radioactive service, or to make the melter easily repaired: the design focused on demonstration of the combination of slurry feeding and stirred melting. Details of the design and testing are given in reference 22.

The measured slurry melt rates with the new design are 155 kg m^{-2} h^{-1} with agitation (32 lb ft^{-2} h^{-1}), and 19.5 kg m^{-2} h^{-1} (4.0 lb ft^{-2} h^{-1}) without agitation. This demonstrates an increased melt rate by a factor of 8, similar to the factor calculated from the Owens-Illinois stirred melter tests of commercial glass from raw materials [21]. The demonstrated melt rate was limited by the ability of agitation to disperse the slurry as it was sheared by the underlying foam. Estimated electrode current densities indicate that an additional factor of 2 increase is possible before electrode current is limiting melt rate. It is therefore concluded that melt rates of about 290 kg m^{-2} h^{-1} (60 lb ft^{-2} h^{-1}) are possible through design optimization.

Since this design uses all metal glass contact materials, only 2 melter pieces contact the molten glass. Replacement of the tank or agitator is possible, minimizing disposal volumes and costs. Thus, this design combines the most desirable features of the continuous pot melters and the slurry-fed ceramic-lined melters.

SUMMARY

Advances have been made in the ability to restore inoperable waste glass melters. The ability to drain, repair and return slurry-fed ceramic-lined melters to operation is possible based on Scale Glass Melter draining and restart tests. Conceptual designs have been developed to permit the replacement of the riser/pour spout and bottom drain valve assemblies from cooled melters. An alternative drain valve has been designed to provide increased assurance of melter draining in the event of accumulation of noble metals or other deposits on the melter floor.

Melter size can be minimized when the reacting batch is sheared. A new class of waste glass melters has been designed, and proof of concept tests completed on simulated High Level Radioactive Waste slurry. Melt rates have exceeded 155 kg m^{-2} h^{-1} with slurry feeds (32 lb ft^{-2} h^{-1}), and 229 kg kg m^{-2} h^{-1} with dry feed (47 lb

$ft^{-2} h^{-1}$) . This is about 8 times the melt rate possible in conventional waste-glass melters of the same size. Melt rates of about 290 kg $m^{-2} h^{-1}$ (60 lb $ft^{-2} h^{-1}$) are expected to be possible through design optimization.

The agitated melter combines the most desirable characteristics of the continous pot melters and the slurry-fed ceramic-lined melters. Such a design could provide the basis for the development of a generic waste-glass melter capable of converting high level, transuranic, alpha, beta/gamma, chemical (RCRA) wastes, and mixed radioactive/chemical wastes. Agitator optimization is desirable, and detail mechanical design is required before the proof of concept melter can be adapted to actual waste.

The proof of concept melter is full scale for glove box conversion of plutonium or transuranic wastes. Since all glass contact materials are metallic it is possible to scale the melter to meet the HLW melter needs of WVDP (~2 ft square) or DWPF and HWVP (~2.5 ft square with optimized agitator).

Acknowledgements- Members of the Advanced Melter Program Plan Task Team were M.D. Boersma (chairman), D.F. Bickford, J.R. Glasscock, M.W. Grant, J.D. Gutman, Jr., C.A. Nash, M.J. Plodinec, T.G. Powell, and W.W.F. Yau. Additional economic evaluations were conducted with W.R. McDonell. The Agitated Waste-Glass Melter and Alternative Drain Valves are joint developments and demonstration with Mr. Ray Richards, President, Associated Technical Consultants, Toledo, OH . Inconel 690 is a trademark of Inco Alloys International. This work was conducted under Contract No. DE-AC09-88SR18035 with the US Dept of Energy.

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[21] R.S. Richards,"Rapid Glass Melting and Refining System", Advances in the Fusion of Glass (Am. Cer. Soc. 1988) 50.1-50.11 . See also U.S. Patent No. 3,988,138, October 26, 1976, "Method and Apparatus for Melting Glass-Making Materials".

[22] R.S. Richards," Small High-Speed Glass Melter for Waste Vitrification", Am. Cer. Soc., Dallas TX, April 1990.

[23] Inco Alloy Handbook, Inco Alloys International, undated.

TABLE 1:
COST INCENTIVES FOR INCREASED ATTAINMENT OR INCREASED INSTANTANEOUS PRODUCTION RATES

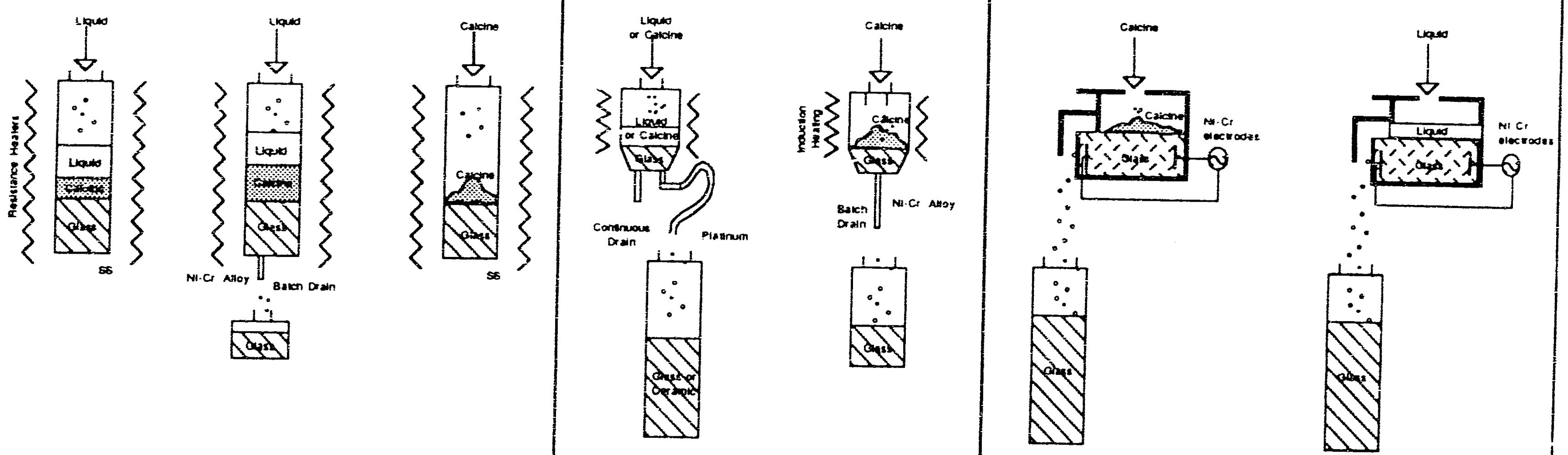
UTILITY,%	CAN./YR.	YEARS	DIFF. IN COSTS, $MM
50	273	25	+470
70	383	17.8	+63
75	410	16.6	REF.
76	415	16.4	-12.3
80	437	15.6	-57
90	492	13.9	-155
100	547	12.5	-230
125	683	10.0	-370

TABLE 2 : <u>ADVANCED DWPF MELTER GOALS AND INCENTIVES</u>

Priority	Goal	Incentive, $MM
1	Ensure that early melters achieve design objectives	25-50
2	Increase melter performance (ave. production rate) 25%	100
3	Increase waste loading from 28 to 35 wt% (offsite saving to U.S. DOE)	250
4	Minimize spent melter storage and decommissioning	Not Determined
5	Increase melter life / cost ratio	10
5	Recover noble metals in waste (Ru, Rh, Pd, Ag)	35

HISTORICAL SUMMARY OF GLASS MELTING TECHNOLOGY

BATCH			CONTINUOUS MELTER POT		JOULE-HEATED CERAMIC MELTERS	
					CALCINE FED	LIQUID FED
1 Feed liquid continuously while calcining and vitrifying	1 Feed liquid 2 Calcine 3 Vitrify	1 Spray calcine 2 Vitrify continuously	1 Spray calcine or conc. liquid 2 Vitrify continuously	1 Rotary kiln calcine 2 Vitrify continuously	1 Spray calcine 2 Vitrify continuously 3 Direct heating by electrodes in glass	1 Feed liquid and vitrify continuously 2 Direct heating by electrodes in glass



Countries						
CANADA UNITED KINGDOM	FRANCE INDIA ITALY	USA	USA WEST GERMANY	FRANCE	USA DENMARK WEST GERMANY JAPAN	USA WEST GERMANY JAPAN USSR
Radioactive Demonstration						
1964	1969	1978	1970	1978 *Production*		1985 *Production*
Research Activities						
1956-1968	1962-PRESENT	1966-1982	1959-1974	1970-PRESENT	1962-1980	1976-PRESENT

Adapted from McElroy, Bjorklund, and Bonner

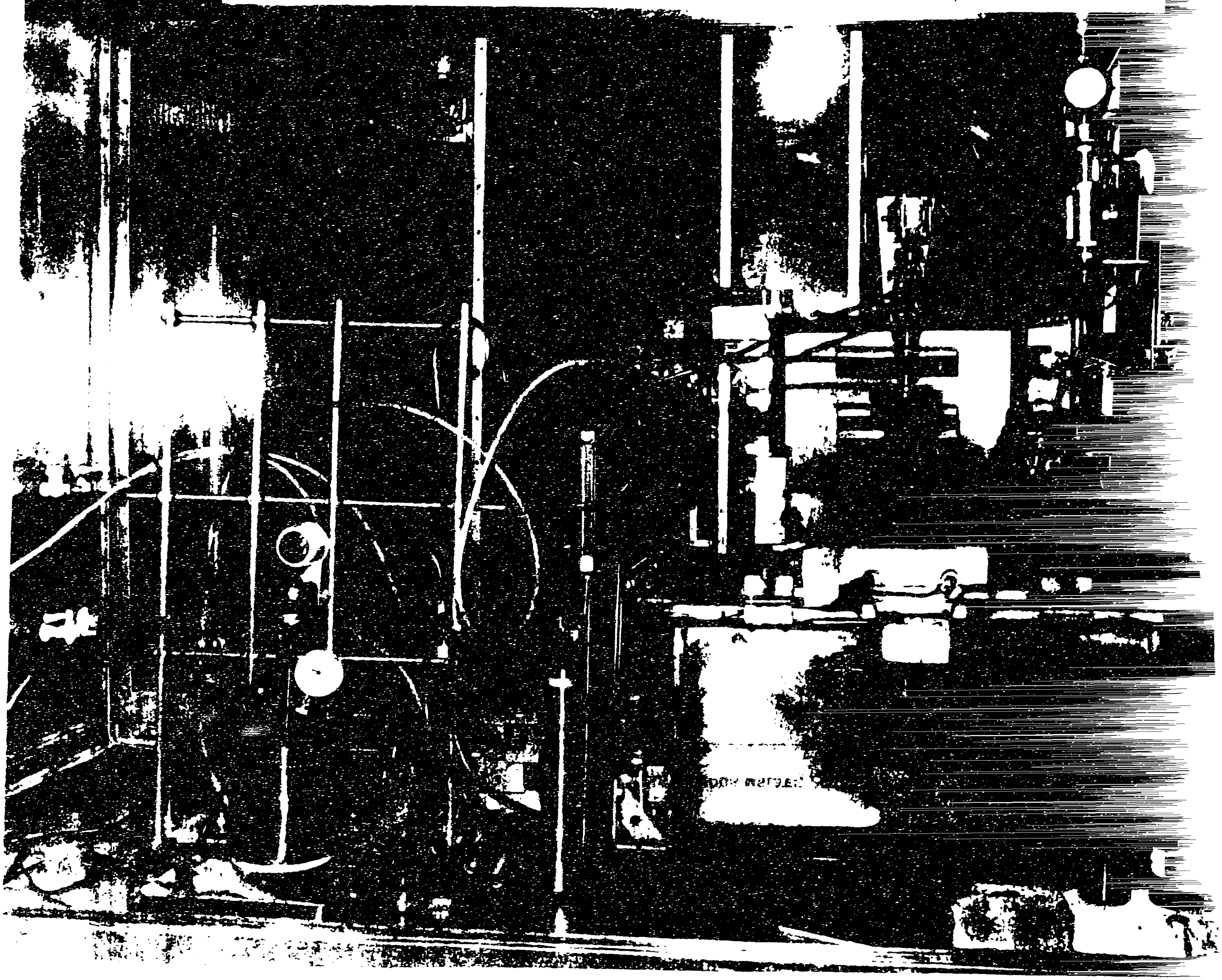
WASTE TYPES	DURABILITY	STABILITY	LOADING	VOLUME REDUCTION	CHEMICAL DESTRUCTION	NEUTRON ABSORBER	RAW MATERIALS COSTS	SMALL SCALE	LARGE SCALE	PORTABILITY	DRAIN / RESTART	GENERIC LICENSING	MELTER COSTS	MELTER DISPOSAL	PRODUCT SAMPLING
HIGH LEVEL (Cs, Sr, Pu, U)	●	●	●		●				●		●		•	●	•
β–γ WASTES (U, EU)	●	●	●	•		●	●	•	●	•	•	•	●	•	•
α WASTES (Pu238, Pu239)	●	●	•	●	●	●		●	•		●		•	●	●
TRU WASTES (, Np, Pu, Am, Cm)	●	●	●	•		●	•	●			●		•	●	●
MIXED WASTES (Rad & Chem)	●	●	•	●	●	•			●		•	•	•	●	●
HEAVY METALS (Pb, Cd)	•	●	●				●	●	•	●	●	●	●	•	•
INORGANICS	●	●	•	●	●		●		●	●	•	●	●	•	•
ASBESTOS			●	•	●		●		●	●		●	●		
ORGANICS				●	●		●		●	●		●	●		
DISARMAMENT (Pu, EU)	●	●	●			●		●			●			●	●

SUMMARY OF ADVANCED MELTER APPLICATIONS

PROGRAMS / GOALS	MEET DESIGN GOALS	INCREASE RATE 25%	INCREASE LOADING 25%	STORAGE & DECOMMISSIONING	MELTER LIFE / COST	NOBLE METAL RECOVERY	PROCESS β–γ INCINERATOR ASH	DERATE HAZARDOUS WASTE	DERATE MIXED WASTES	PROCESS α ASH	PROCESS α WASTE
SCALE MELTER DRAIN / RESTART	●			•	●	●					
RISER REPLACEMENT	●			•	●						
ATC/SRL BOTTOM DRAIN	●			●	●	●					
NM ELECTRICAL MODEL	●				●	●					
NM CHEMISTRY STUDIES	●				●	●					
NM FLUIDITY STUDY	●				●	●					
LID HEATER REPLACEMENT	●				●						
MELT REACTION STUDIES	●	●	●		●	●	•	•	•	•	•
STIRRED MELTER	●	●	●	●	●		●	•	•	●	●
EPA TOXICITY TESTS	●						●	●	●	•	•
SMALL MELTER OFF GAS SYSTEM							●	●	●	•	•
ORGANIC COMBUSTION	●						•	●	●	•	●
STAGED REACTION MODEL	●	●	●		●	•	●	●	●	●	●
MELTER REDOX MODEL	●				●	●	•	●	●	•	●
Cr ELECTRODES		●	●				•	●	●	•	•
WASTE VOLUME REDUCTION							•	●	●	•	●
WASTE COMBUSTIBLES REDUCTION								●	●		●

Melters Used to Assess Design Features and Operating Procedures

Lab-Scale Melter



<u>ADVANCED MELTER PROGRAM TASK TEAM</u>

EVALUATED MELTER IMPACT AND RISK TO DWPF OPERATING COSTS

CONSIDERED OTHER ANALYSES OF OFFSITE COSTS

RANKED GOALS AND INCENTIVES

<u>MELTER CONCEPTS CONSIDERED</u>

BASE LINE- NO CHANGE

ADVANCED MELTERS

- IMPROVED- EVOLUTION OF PARTS OF MELTER
- MODULAR- HIGHER COST, MORE REUSEABLE
- DISPOSABLE- LOW COST, SHORTER LIFE, EASY CHANGE OUT AND DISPOSAL

<u>CONCLUSION</u>: EXPECTED SAVINGS $100 MILLION IN DWPF IF USED AFTER 4^{TH} OR 5^{TH} BASELINE MELTER. ADDITIONAL SAVINGS POSSIBLE FOR OTHER GOALS.

ADVANCED DWPF MELTER GOALS AND INCENTIVES

Priority	Goal	Incentive, $MM
1	Ensure that early melters achieve design objectives	25-50
2	Increase melter performance (ave. production rate) 25%	100
3	Increase waste loading from 28 to 35 wt% (offsite saving to U.S. DOE)	250
4	Minimize spent melter storage and decommissioning	N. D.
5	Increase melter life / cost ratio	10
5	Recover noble metals in waste (Ru, Rh, Pd, Ag)	35

RISKS TO DWPF MELTER OPERATION

OVERHEAT INCONEL 690

6 MONTHS- 6 YEARS: SULFIDATION OF LID HEATERS OR POUR SPOUT

6 MONTHS-8 YEARS: ELECTRODE CREEP

1-3 YEARS: NOBLE METAL ACCUMULATION (AT AVERAGE CONCENTRATIONS)

2 YEAR: DESIGN LIFE

2-6 YEARS: LID HEATER CREEP, HOT SPOTS, ELECTRIC TRANSFORMERS

2-4 YEARS: RISER POUR SPOUT WEAR

4-8 YEARS: REFRACTORY WEAR & SPALLING

6-12 YEARS: ELECTRODE WEAR / WELD ATTACK

CONCLUSION: GREATEST RISK IS OVERHEATING
2ND GREATEST RISK IS LOCAL CREEP OR LOSS OF INCONEL 690.

<u>DWPF MELTER:</u>

SCALE MELTER- FULL SCALE RISER/ POUR SPOUT, SHORT LID HEATERS, 40% MELT AREA OPERATED, DRAINED, RESTARTED, SHUTDOWN, RESTARTED, DRAINED

DWPF BASELINE- 1 INSTALLED, 1 SPARE NEAR COMPLETE, 1 ORDERED

DWPF BASELINE IS DESIGN REFERENCE FOR HWVP

DWPF SCALE MELTER SAME RATE AS WVDP MELTER.

Potential Benefits of HLW Glass Technology to Other Wastes

Well characterized waste form stability
Extremely low release rates in a variety of environments
Excellent mechanical and thermal stability
No combustible or pyrophoric properties in waste form
Retention of essential release properties even if damaged
Low generation of potentially respirable particles
Ability to accept high loadings of heavy metals
Ability to accomodate fluctuating waste compositions
Ability to combust limited amounts of organics (including carcinogenics)
Total destruction of asbestos
Scale of facility adaptable

Potential Applications to Other Wastes

Derate chemical hazardous wastes to non hazardous forms
heavy metals, carcinogenics, asbestos, inorganic and organic poisons

Derate mixed hazardous wastes to low level radioactive wastes
destroy organics, bind up inorganics

Process high activity β–γ incinerator ashes

Volume reduction of β–γ, chemical and mixed wastes

Convert Pu glove box wastes to compact, stable and durable forms

SRL/CWRU/WVDP Melt Reaction Studies

For waste glasses normally melted at 1150°C:

- Foaming reactions complete ~950°C
- Primary redox reactions complete 950°C - 1 hr
- SiO_2 dissolution complete 950°C - 1/2 hr
- Durability essentially achieved by 950°C -1 hr
- Foam removal requires 2 hr > 1050°C

Conclusions: Waste glass melters can be operated

- ~1050°C with residence time ~ 2 hr
- Inconel 690 (TM) can be used for stressed components
- Agitation could convert melting from surface to bulk process
- Agitation will increase the melt rate of waste glass

RAMAR

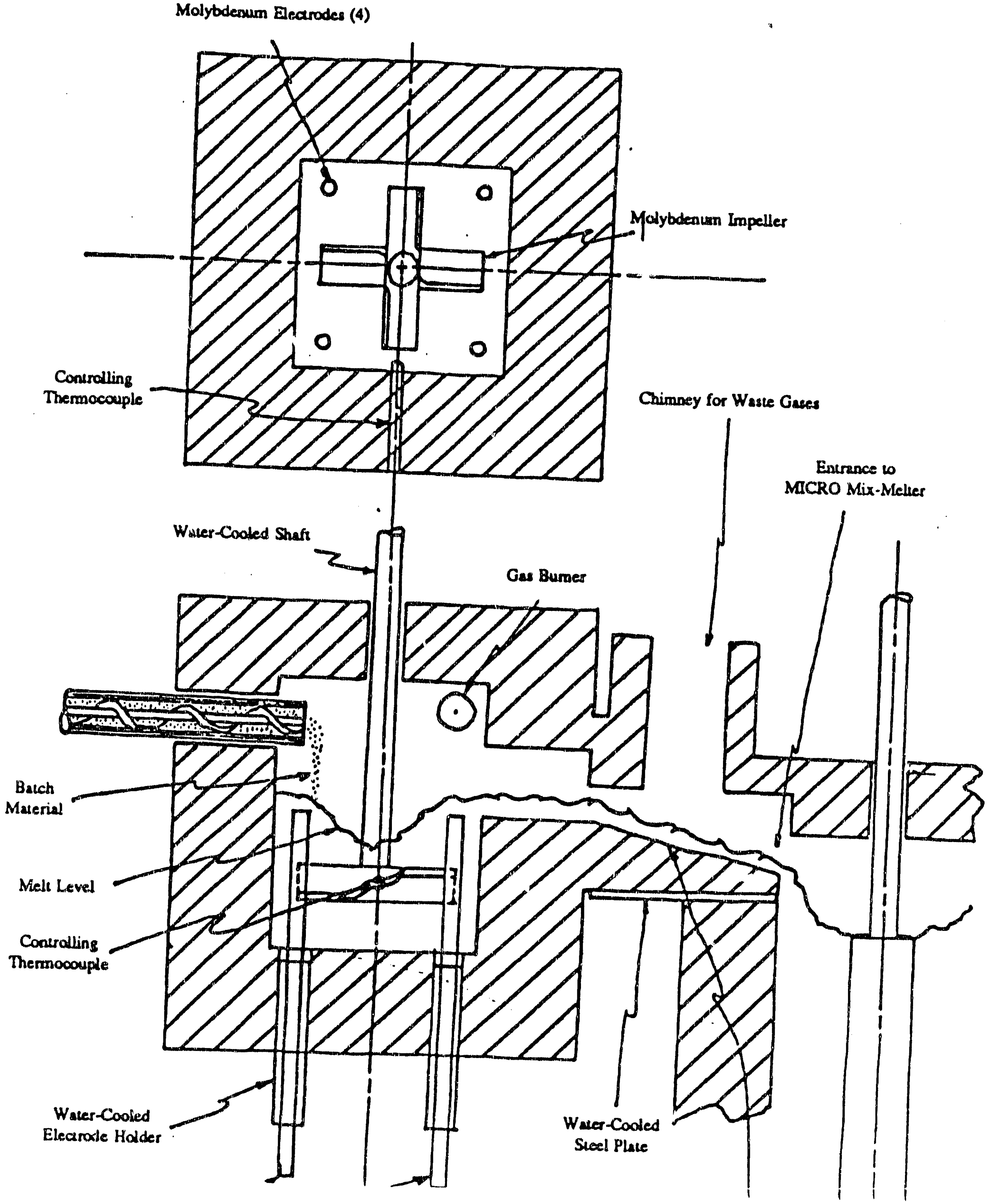
(Owens-Illinois RApid Melting And Refining Project, first stage)

Advantages

- Compact 2 ft cube melt chamber
- Demonstrated 24,000 pounds per day
- Simple geometry
- Simple mechanical drive system
- Rapid Start, Drain, Restart

Design changes

- Slurry feeding
- Premelted frit additions
- Eliminate foam glass output
- Prevent unreacted material from leaving melter
- Limited Materials/Operating Temperature
- Eliminate glass contact refractories
- Restrict glass contact materials to Inconel 690 (TM)
- All electric startup and melting
- Assure organic combustion



Molybdenum Electrodes (4)
Molybdenum Impeller
Controlling Thermocouple
Chimney for Waste Gases
Entrance to MICRO Mix-Melter
Water-Cooled Shaft
Gas Burner
Batch Material
Melt Level
Controlling Thermocouple
Water-Cooled Electrode Holder
Water-Cooled Steel Plate

ATC / SRL Agitated Melter Design Concepts

Inconel 690 (TM) Agitator (Electrode)
1 foot square Inconel 690 Glass Tank with overflow (Electrode)
External lid heaters for startup and melt rate boosting

ATC / SRL Agitated Melter Test Results

Slurry feeding viable
- minimal splatter & entrainment
- better dispersion of slurry drops desirable

High melt rates: 32 pounds per hour with slurry (1 sq. ft.)
47 pounds per hour with dry feed

Negligible wear or deformation of Inconel 690

Foam free waste glass

Heated baffle effective in reducing entrainment

ATC / SRL Agitated Melter Test Implications

DWPF & HWVP production melter could be ~2.5 foot square

1 foot square test unit was full scale for ~50 pound/ hr Pu ash melter

END

DATE
FILMED
9/11/92