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DEVELOPMENT OF GLASS MELTER FOR THE PNC TOKAI VITRIFICATION FACILITY

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Abstract

The development of the glass melter which will be used in the HLLW vitrification facility has been performed since 1977.

The design and operational experiences has been accumulated through the process tests in the cold engineering facilities. The results obtained in these periods have been considered in the design of the Tokai Vitrification Facility (TVF), the construction of which has already been started in the spring of 1988.

The present PNC melter system includes several features as the result of PNC's own improvements and modifications. The results of the melter development will be described in this paper mainly on the special features which are developed in PNC, such as glass fiber additives, induction-heated bottom drain nozzle and remote handling technique. The mock-up test using the new mock up melter which was constructed following the TVF final design has started to verify the process performance.

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ガラス固化技術開発施設のためのガラス溶融炉開発

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要 旨

東海再処理工場の運転に伴い発生する高レベル廃液を固化処理し，併せてプラント規模のガラス固化技術を実証する目的で，ガラス固化技術開発施設（TVF）の建設が進められている。

ガラス溶融炉は，ガラス固化プロセスの中心となる機器であり，構造上，運転上の信頼性を向上させるため，1977年以来ETF，MTFにおいて，実スケールの溶融炉を用いた技術開発を行って来た。

本報では，溶融炉技術に関して，動燃で開発した成果が顕著である下記のテーマを中心に，開発の経緯を述べる。

(1) 導電性スラッジの滞溜を防止する，炉構造及びガラス抜き出し技術。

(2) ガラス繊維原料を用いる，液体供給メルタ技術（LFCM）

(3) 溶融炉の遠隔操作，及び廃メルタの遠隔解体技術。

これらの技術開発成果をTVFのプロセス設計に反映し，TVFの運転・保守の信頼性向上に結びつけた。

なお，本報はアメリカ原子力学会廃棄物トピカルミーティング"SPECTRUM '88"に於いて発表した。

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CONTENTS

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ABSTRACT

Power Reactor and Nuclear Fuel Development Corporation (PNC) has developed Liquid Fed Joule-heated Ceramic Melter (LFCM) for the HLLW vitrification process since 1977. Technology development includes design of melter structure to prevent the accumulation of deposits, induction-heated bottom drain nozzle, liquid-fed process with glass fiber additives, and associated monitoring instruments. Related technology development such as remote maintenance and decomissioning have also been done. In this paper, the fruit of melter development experiences will be described.

I. INTRODUCTION

The vitrification process technologies have been developed in PNC since 1977. PNC process is based on the Liquid Fed Joule-heated Ceramic Melter.

Many activities on LFCM process development have been carried out in the full-scale cold tests through the operations of the Engineering Test Facility (ETF) and Mock up Test Facility (MTF) started in 1980 and 1982, respectively.

Currently, the groundpreparation for the Tokai Vitrification Facility (TVF) was started after completing the detailed design, design improvement and getting the license from regulatory agency of the government. TVF will start operation in 1992. Table 1 shows the masterschedule of TVF.

The joule-heated ceramic melter, which is based on the melter commercially used in glass industry, is a main equipment in the LFCM process. In the developmental work, melter has been modifed to be more suitable for adapting the vitrification process by adding PNC's own improvements and modifications.

Figure 1 shows the PNC experiences of melter construction and operation in relation with TVF schedule.

II. DESCRIPTION OF PNC MELTER DEVELOPMENT

There are several development subjects in the ceramic melter system when it is adapted to the vitrification process. Major development items carried out for the PNC melter system are listed in Table 2.

In the earlier stage of the development, melters with different structures and materials were tested to compare their process characteristics. Then melter design has been modified to improve the LFCM process performance. Melter structure with sloped floor, glass additive using fiberglass frit, and freeze valve drain with two-zone induction heating are the major results being adopted in the final design.

In the mock-up test, melter constructed in 1987 following the TVF final design has started operation in connection with whole process equipments. Photograph 1 is the new mock-up melter placed in the simulated remote cell.

II-1 MELTER STRUCTURAL DESIGN AND OPERATION

In the LFCM process, melter refractory design should be optimized mainly considered with temperature, heat balance, glass flow and also the behavior of immiscible deposits which is electroconductive.

Several experiments, about the slope of melter bottom were performed using lab.-scale melters in order to avoid the operational problem caused by the accumulation of electroconductive deposits which is consist of noble metal elements. The result showed that the melter bottom slope of 45° would evade the operational difficulties by facilitating the discharge of the deposit.

In order to confirm above result, melter operations have been carried out using full scale melters with a bottom drain at 45° sloped bottom. Operation tests using highly simulated waste, each test includes 3 to 8 days of continuous feeding, have been carried out to evaluate the influence of conductive deposit on melter operation.

It was found that no significant change has been observed in joule-heating between main electrodes and more than 90% amount of noble metal elements fed into the melter was discharged through the bottom drain. The short circuit phenomena that cause the operational problem of joule-heating could be eliminated.

II-2 LIQUID WASTE AND FRIT FEED TECHNOLOGY

In the development of liquid waste and frit feed technology, powdered and granular glass (beads) additives have been attempted to use in the LFCM process in the earlier stage of the development.

In view of stable melter operation, new glass additive forms have been developed in considered with reducing the amount of particulate to prevent the off gas line plugging as well as to keep good product glass quality. Glassfiber additive and its continuous feed system have been developed in place of former two types of glass frit.

In Table 3, the specifications of each type of glass frit are described. After the continuous operation tests using glassfiber additives producing more than 10 tons of simulated waste glass, LFCM using cylindrical glassfiber additives was adopted for TVF process.

In the stable feed operation, entrainment of particle in the off gas stream was reduced up to 1/10 compared with that of the feed operation using beads frit, as shown in Figure 2. It was also found that the glassfiber additive made the glass melting be stable and moderate without abrupt evaporation of the water on the melting surface.

The size of the cylindrical glassfiber additive is typically 70mm in diameter and 70mm in length. The fiber diameter is about 10 microns. The liquid holding capacity of glassfiber additive is 4 ml/g at the maximum. The characteristics of the glassfiber additive made by sintering have been optimized with respect to the liquid holding capacity and transportation ability in the feed system.

Photograph 2 shows the outlook of the cylindrical glassfiber additives currently used in the engineering scale process.

II-3 DRAIN SYSTEM DEVELOPMENT

Drain system has been developed to have good operation and maintenance ability. Two types of glass drain freeze valve have been demonstrated. One is a direct current heating type with mechanical stopper for glass flow at the termination of glass drain, the other is an induction heating type. The features of the above two drain systems and test results are summarized in Table 4.

From the standpoint of the simplicity of system and operation and especially of its expected long lifetime of the drain pipe, the freeze valve with induction heating has been further developed and modified.

The point of the development was to eliminate the formation of glass string at the termination of glass drain.

As the result, freeze valve with two-zone induction heating, which gives the heating to the tip of the drain independently, was found to be effective to eliminate the formation of glass string. This concept has also been introduced to the TVF design.

Figure 3 illustrates the present design of the bottom freeze valve with two-zone induction heating.

II-4 HEATING SYSTEM DEVELOPMENT

The melter should have auxiliary heating system for start-up operation besides electrodes for joule-heating. Heater units which have conventional SiC resistance heater inside the Inconel jacket are used in the present design.

Microwave heating is now under development as a promising alternative heating technique in the future. It is expected for both to increase melting capacity when using in feed operation and to simplify melter superstructure by eliminating heater units.

II-5 INSTRUMENTATIONS

Ceramic melter is equipped with several instrumentations to monitor the operation status including temperature, pressure, and electrical conditions which is listed in Table 5.

Instrumentation which is typical for PNC melter is the molten glass surface detection system based on electrical resistance measurement between the detection prove and glass. The system has been developed and improved to get enough reliability in measuring the glass level within 10 mm.

Figure 4 shows the system concept of currently tested detection system. The change of the electrical resistance is analysed based on the time difference of the resistance to eliminate the effect of glass temperature and composition which affect the glass resistance.

II-6 REMOTE MAINTENANCE

Many activities on the remote maintenance have been carried out in the development of LFCM process because that remote maintenance is necessary for melter parts and melter body which are supposed to have short lifetime compared with that of the plant.

Remote maintenance is applied to the following components; the melter components such as the heating units for start-up, connections in the feed line and off gas line, and instrumentations like thermocouples. As the remote handling tools, in-cell cranes and two-armed servo-manipulators will be equipped to be able to make in-situ maintenance. Melter itself can also be replaceable by disconnecting from the supporting frame.

To improve the remote design of the melter components, remote handling tests have been carried out using a simulated melter structure and remote handling tools in a simulated remote cell. As the result of these tests, most suitable remote design and handling procedure for each melter component have been confirmed.

II-7 RELATED TECHNOLOGIES

Ceramic melter will become a new large size solid waste with high radioactivity after its lifetime. Therefore, dismantling technologies for ceramic melter have been developed aiming to be able to handle and store it by the same procedure as the other high-level solid waste by disassembling it into small pieces.

The results of remote dismantling tests using mock-up melter served in actual cold operations have been considered in the design of handling devices in the dismantling cell which is planned to be provided for the TVF.

The thermal and flow analysis of molten glass by computer modeling have been performed to evaluate the melter characteristics, and to utilize it in the melter design work. Extended work in computer analysis is still continued to apply it to the process control of melter system.

As an attempt to extend the operation life of ceramic melter, fundamental research on refractory and electrode materials has been carried out to improve the corrosion resistance to the molten glass. Some improved ceramic materials, which have both adequate high electrical resistance compared with that of the molten glass and more corrosion resistance than presently used Cr_2O_3-Al_2O_3 refractory, have been found in laboratory-scale test.

III. CONCLUSION

Many R&D activities have been carried out on the ceramic melter technology to attain the most suitable LFCM process for TVF. As the result, the present melter for TVF is designed to eliminate the operational difficulties in liquid fed operation and glass melting with noble metal. A reliable bottom drain with induction heating and remote handling technique has also introduced in the final design.

Table 6 shows the design requirements and the resulted design data for the TVF operation melter. The sketch of the final melter design is shown in Figure 5. The new mock-up melter which is designed following this final design has already started operation in the beginning of 1988 to demonstrate its process performance.

Further development of melter materials and microwave technique for the advanced melter shall be kept up to establish higher process capacity and longer operation life. Minimizing the secondary waste and reducing the total life-cost of melter are the next goal in the future development.

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Table 1 Schedule of TVF

ITEM \ F.Y.	1986	1987	1988	1989	1990	1991	1992	1993
Safety License Application and Permission	▼	▼						
Building Construction			■	■				
Equipment Manufacturing and Installation			■	■	■			
Cold Test Operation					■	■		
Heat Operation							■	■

Table 2 Subjects of PNC Melter Development

Melter structural design	Glass pool design to prevent the accumulation of conductive deposit
Glass frit form	Glassfiber frit to reduce particulate entrainment in melter off gas
Glass drain technique	Freeze valve type bottom drain with two-zone induction heating
Auxiliary heating system	Heating-up method with good remotability
Instrumentation	Molten glass level detection
Dismantling of ceramic melter	Dismantling of melter using remote disassembling tools

Table 3 Glass Additive Forms

Spec. \ Form	Powdered Frit	Bead Frit	Fiberglass Frit
Particle Size	~10μ ≥50% 10~40μ <50% 40~44μ < 1% 44μ~ 0%	1~2mm <50% 2~2.8mm ≥50% 2.8mm~ 0%	Fiber diameter 9~12μm Add. form (Cylinder) 70mm dia.×70mm length 60±2g/piece
Density (g/cm^3)	•Glass density 2.4 •Bulk density 1.0	• ← •Bulk density 1.65	• ← •Bulk density 0.2

Table 4 Description of Freeze Valve Drain Ever Developed

Heating Method	Direct Resistance-heating	HF Induction Heating
Material	Inconel	Inconel
Termination of Glass Flow	Air Cooling and Mechanical Stop	Air Cooling and Mechanical Stop ↓ Air Cooling and Two-zone Heat Control without Mechanical Stop
Results	·Thin Pipe Structure for Resistance-heating is not Compatible with Required Lifetime and Strength Necessity of Stop Mechanism	·Elimination of Stop Mechanism by using Two-zone Heating ·Maintenance of HF Heating Coil

Table 5 Monitoring for Safety Operation of Melter

Monitoring Items	Methods
Refractory Temperature	·Thermocouples in Glass-Contact Refractory
Electrode Temperature	·Thermocouples in Electrode
(Glass Temperature)	·(Estimation from Refractory/Electrode Temperature)
Feed Rate and Melt Condition of Feed	·HLW Feed Rate : Feed Tank Level ·Frit Feed Rate: Count the Number of Glassfiber Frit ·Plenum Temperature ·ITV Observation
Joule-Heating(Power)	·Voltage ·Current ·Resistance
Plenum Pressure	·Pressure Gauge
Molten Glass Leakage	·Metal Shell/Glass Electrical Resistance
Molten Glass Level Detection	·Electric Resistance between Detection Probe

Table 6 Design Requirements for Glass Melter

Operating Temperature	1100°C-1200°C Max. 1250°C
Production rate	8.8kg-glass/hr
Feed Material & Feed Rate	Conditioned HLLW, 15ℓ/hr (150g-oxide/ℓ) Fiberglass Additive 6.6kg/hr
Glass Discharge Method & Discharge Rate	Bottom drain, 300kg-glass/2hr
Discharge Frequency	Every 34hr
Operation Lifetime	5yrs

MELTER DATA of THE FINAL DESIGN

Outside dimension	1.9m×1.9m×2.3m[H]
Melting surface area	0.66m² (0.8m×0.83m)
Glass pool volume	Max. 350 ℓ
Electrode	Main electrode: 1 pair, Inconel 690® plate Auxiliary bottom electrode: 1 pair, Inconel 690® Rod
Refractory	Glass contact: Monofrax K-3® Superstructure: Sintered Al_2O_3-ZrO_2 Back-up, Insulation: Mullite
Heating-up	10 SiC heating elements with Inconel jackets
Glass drain	Induction-heated bottom freeze valve
Feed line	Glass additive, HLLW, Water
Off-gas line	Main and backup line to first scrubber

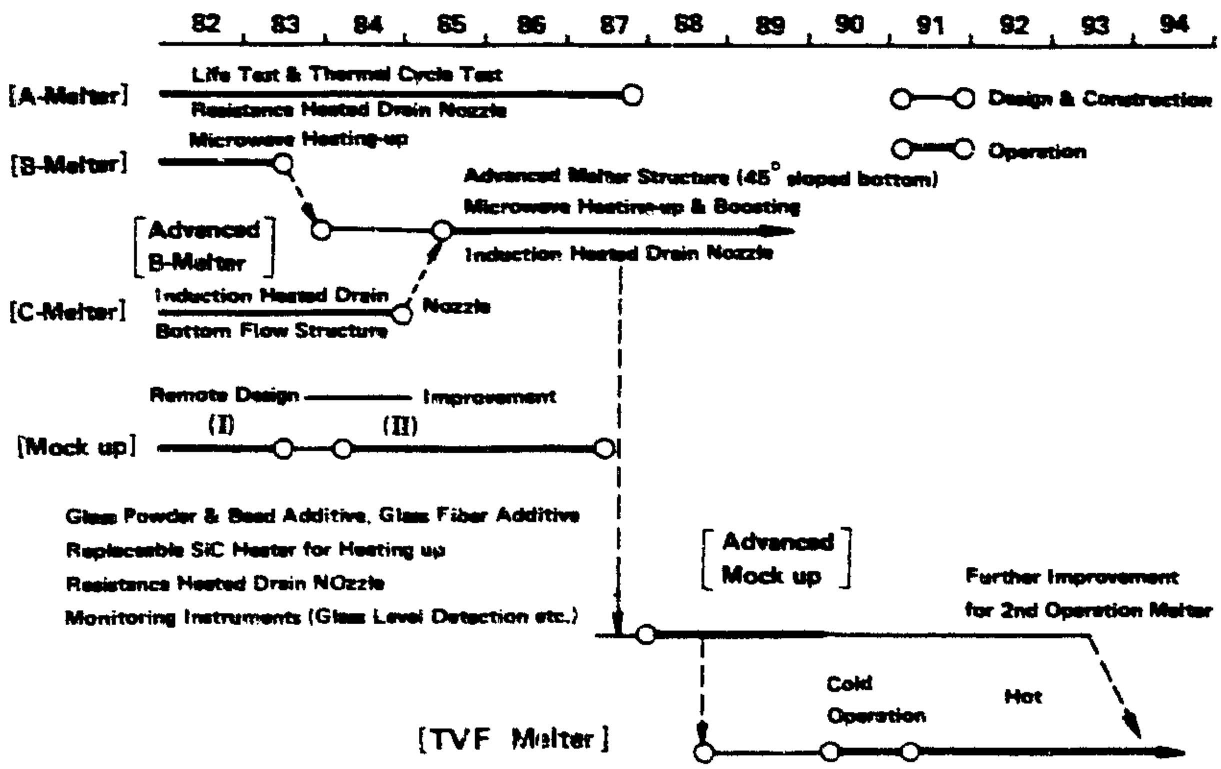

Fig. 1 Melter Development Experiences in PNC

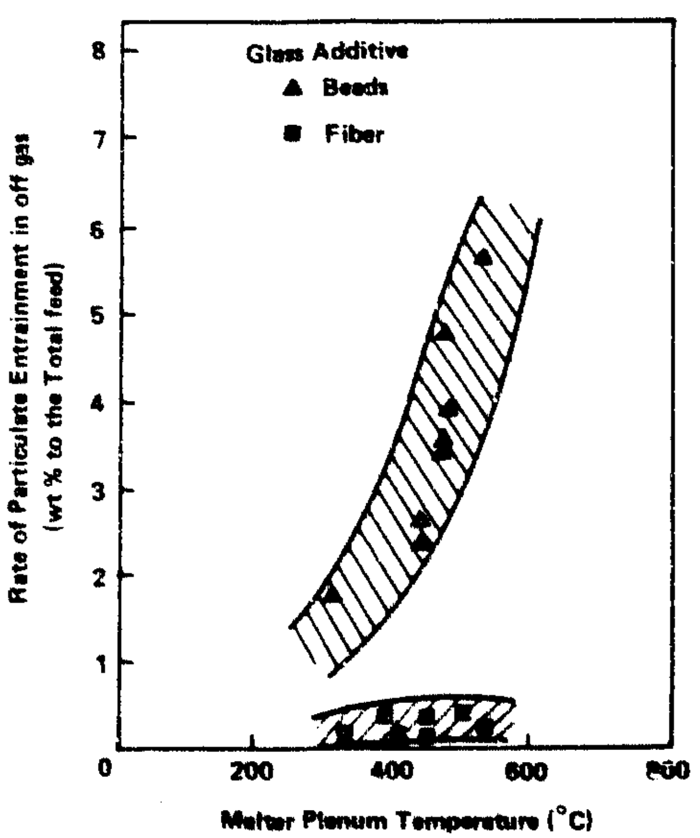

Fig. 2 Effect of the Glass Additive Form on the Particulate Entrainment in Melter Off-Gas

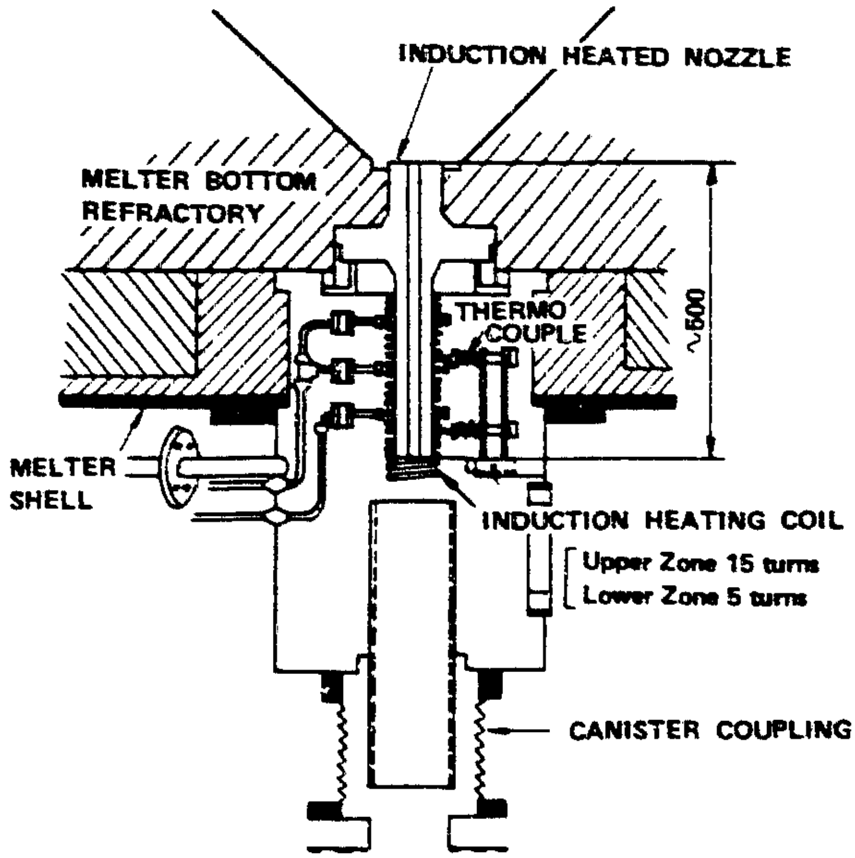

Fig. 3 Two-Zone Induction Heated Drain Nozzle

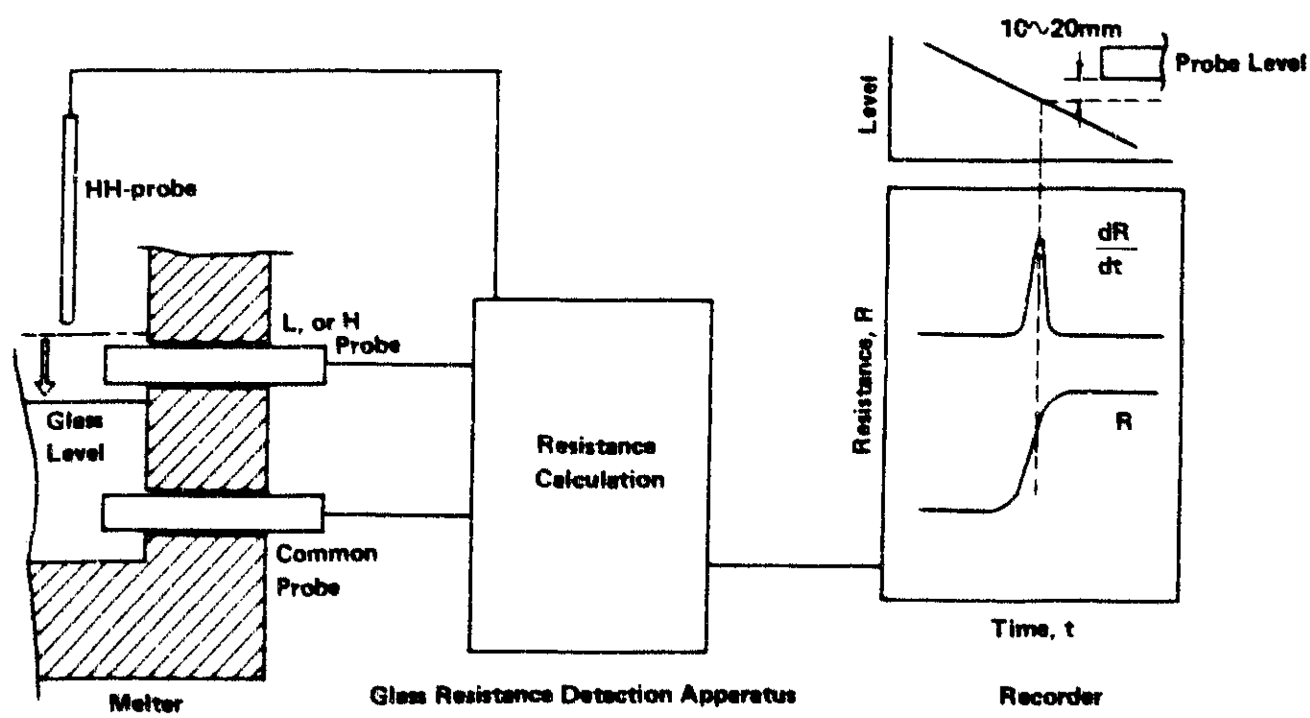

Fig. 4 Glass Level Detection of Melter

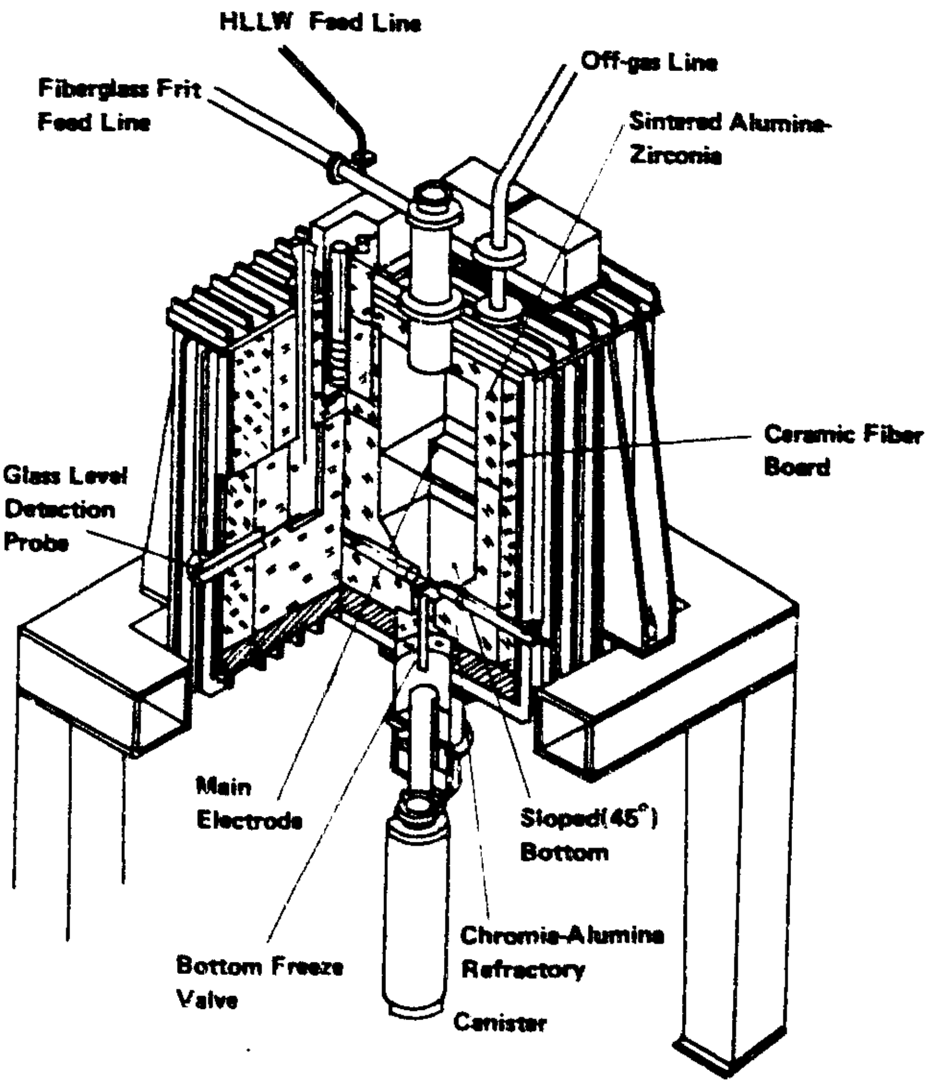

Fig. 5 Structure of Melter

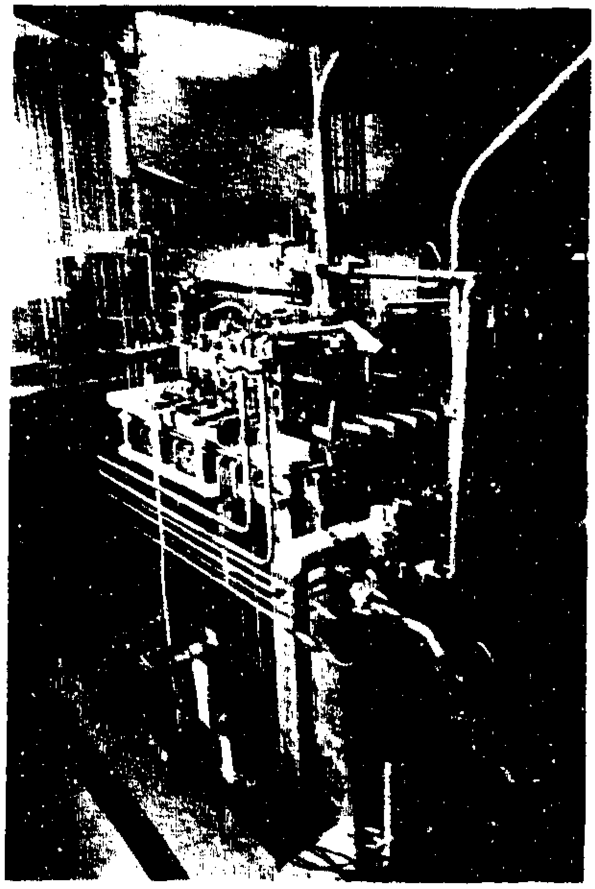

Photo. 1 Mock-up melter placed in the simulated remote cell

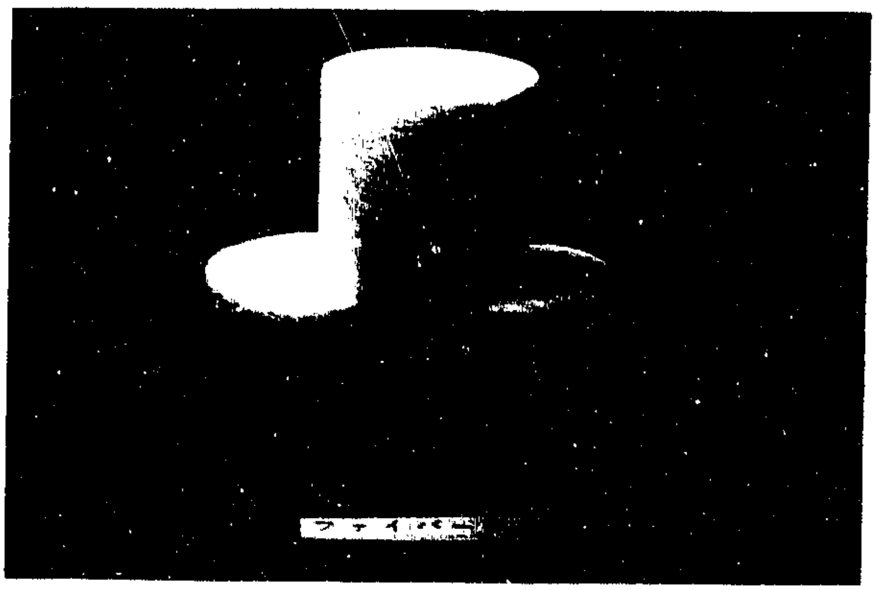

Photo. 2 Glassfiber Additive