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Původní práce

TECHNICAL GLASSES: ELECTRICAL PROPERTIES AND BEHAVIOUR IN NUCLEAR REACTOR VVR-S

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The technical glasses SIMAX, SIAL, PN, UNIHOST, KS-80, KS-90 were irradiated in the VVR-S reactor and their electrical conductance was measured. The decrease of conductance was found after irradiation by thermal neutron fluence 2.0×10^{23} n . m^{-2} having characteristical values for different sorts of glasses. In the reactor rig was studied the heat generation in glasses with boron (SIMAX, SUPREMAX) and without boron (UNIHOST). Boronless glass has shown the temperature increment comparable with temperature measurement error. Both borosilicate glasses produced elevation 39 K, resp. 33 K, at the rig operational temperature 350 to 390 °C.

INTRODUCTION

The electrical conductance of common technical glasses in the nuclear reactor radiation field and the additive influence of the high temperature was not systematically studied (see for example 1, 2, 3). So far, the attention was concentrated on the optical properties in such conditions [4, 5]. Electrical conductance was studied only at low, or very low temperature [6, 7]. The endeavour to apply ionic thermometers [8, 9, 10] for in-core reactor instrumentation made imperative to study the insulating properties of glasses in reactor radiation field. At the same time, the actual production of heat in borosilicate glasses and its influence on thermometric properties of the ionic thermometer needed more enlightening. The glasses used for ionic thermometers contain as a rule, some boron. Most frequently used SUPREMAX (DDR) has 5—7 per cent of B_2O_3.

In a thermal neutron field, an intensive nuclear reaction occurs with izotope 10 boron according to equation

$$^{10}B + n = {}^{7}Li + {}^{4}He + \gamma + \Delta H, \qquad (1)$$

where ΔH ... total liberated energy

The magnitude of the liberated energy could be well demonstrated on a hypothetical calculated case of an interaction of 1 gr of pure ^{10}B with thermal neutrons, where 3.1 GJ is carried away by helions and photons and 7.7 GJ is dissipated by hot atoms of ^{7}Li. Both energy carriers interact actually with surrounding glass heating it up. This considerable effect had to be explored in configuration similar to that of ionic thermometer (Fig. 1). The other possible approach to this problem — calculation of the thermal fields, turned out to be more complex and will be reported later.

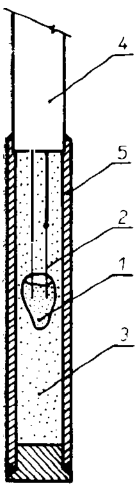

Fig. 1. Usual configuration of the ionic thermometer;
1 — ionic thermometer, 2 — conducting wire, 3 — insulating filling (MgO), *4 — thermocouple cable, 5 — stainless steel cladding.*

EXPERIMENTAL

Electrical conductance experiments

The samples of Czechoslovak technical glasses SIMAX, SIAL, PN, UNIHOST, KS-80, KS-90 (described elsewhere [11]) were prepared in the form of glass drop with platinum contacts (Fig. 2). Such arrangement makes possible to measure only simple conductance, not the specific value. On the other hand the form is very similar to the actual ionic thermometer. The electrical conductance of every sample was measured before irradiation ($G_{b.i.}$) and after irradiation ($G_{a.i.}$). The measurement of the electrical conductance was made by TESLA BM-484 RLC measuring bridge at the frequence 1 592 s^{-1} (10^4 rad). The sample holder used for measurement (Fig. 3) was designed to assure homogeneous temperature field and

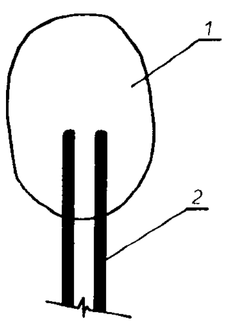

Fig. 2. Glass drop with platinum electrodes for ampoule reactor test;
1 — glass drop, 2 — platinum electrode.

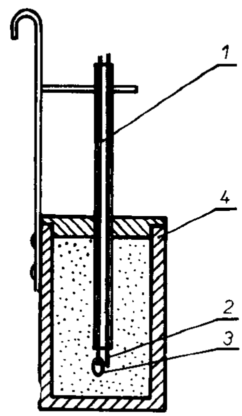

Fig. 3. The sample holder for electrical conductance measurements at elevated temperature;
1 — fourhole-capillary, 2 — thermocouple, 3 — sample, 4 — stainless steel crucible.

lower the radiation hazard as well. The temperature measurement were made by Ni—NiCr thermocouple and digital electrometer DANA 4 800. The conductivity was measured within 150—400 °C which covers well the expected temperature range in reactors VVER.

The radiation experiment in one channel of VVR-S reactor was done in so called "wet can". The samples were covered with aluminium foil, marked and enclosed in quartz ampoule. In this ampoules were placed the dosimetric foils — Cu, Ni for fast neutrons, Co for the thermal ones. After irradiation the samples were uncovered and identified. The dosimetric foils have shown following neutron fluences:

fast neutrons (Cu, Ni) 3.0×10^{23} n . m^{-2}

thermal neutrons (Co) 2.0×10^{23} n . m^{-2}

The electrical conductance of the irradiated samples was measured taking special care at the first measurement, because of irreversible changes in conductance (disappearance of brown colour as well).

Boron heat production experiment

For this purpose a part of the thermometric reactor rig capacity was used (reactor VVR-S, Řež). There different types of glasses (SIMAX — 13 % B_2O_3, SUPREMAX — 7 % B_2O_3 and UNIHOST — 0 % B_2O_3, marked subsequently in Fig. 5 SI, SU, U) were cast in form of a drop on the thermocouple joint. No insulating MgO powder was used, so the thermal barrier was very efficient — static air (Fig. 4). The reactor rig was of usual design [12], equipped by massive aluminium cylinder in which three studied thermocouple assemblies were placed.

The heating was provided by the CHOUCA-T rig system with EUROTHERM temperature controller. Temperature of the aluminium thermometric cylinder was taken by two independent Ni—NiCr thermocouples, calibrated by ZES ŠKODA Works Bolevec, Metrological Laboratory. The arrangement in the cylinder is schematically shown in Fig. 5 (the ionic thermometers, irrelevant to this paper are marked by numbers).

The actual experiment has taken two week cycles (92 and 95 hours) with temperature measurements done at various power levels of the VVR-S reactor.

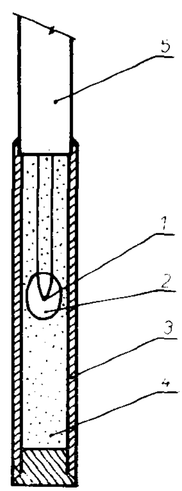

Fig. 4. The alteration of the thermocouple setting for a boron heat production experiment;
1 — thermocouple joint, 2 — glass drop, 3 — air, 4 — stainless steel cladding, 5 — thermocouple cable.

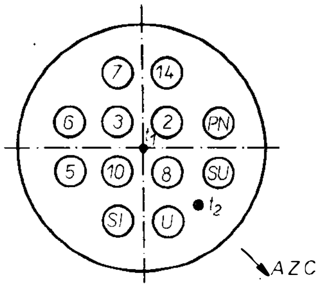

Fig. 5. The distribution of thermocouples with glass drop in Al-cylinder of the reactor rig;

t_1, t_2 — thermocouples, SI — thermocouple with glass SIMAX, SU — thermocouple with glass SUPREMAX, U — thermocouple with glass UNIHOST, PN — thermocouple with glass PN (direction to active zone center — A. Z. C.).

RESULTS AND DISCUSSION

Electrical conductance

The obtained results of electrical conductance measurement were computed using Arrhenius equation

$$\log G = a + b/T, \tag{2}$$

where G — apparent conductance [S],
T — absolute temperature [K],
a, b — constants.

The calculation done by least square routine determined the variance of the a, b values and the residual variance as well.

Using this technique the values a, b were computed for temperatures within 197—400 °C. The lowest temperatures has shown too high error and were not included in further calculations, The values b of the individual regression functions were tested with the use of Student‘s distribution. Values a were not tested because the determined error was too high. The results has shown prevailing agreement for individual measurements and the whole temperature range.

The total volume of the numerical results is available in report [12]. To support our conclusions we have considered adequate the brief summary in the Table I.

Table I

Arrhenius coefficients and conductance evaluated by regression at 523 K of some czechoslovak technical glasses

Glass (type)	before irradiation			after irradiation		
	a	b	$G_{b.i.}$, S	a	b	$G_{a.i.}$, S
SIMAX	0.075	—3.966	3.16×10^{-8}	—1.128	—3.648	1.28×10^{-8}
SIAL	0.484	—3.949	8.69×10^{-8}	—0.599	—3.574	3.74×10^{-8}
PN	1.587	—3.978	9.88×10^{-7}	—1.134	—2.896	2.18×10^{-7}
KS-90	1.449	—3.840	1.29×10^{-6}	1.415	—4.012	5.76×10^{-7}
KS-80	1.438	—3.904	9.70×10^{-7}	0.473	—3.781	1.76×10^{-7}
UNIHOST	0.852	—3.426	2.10×10^{-6}	—0.535	—2.945	6.91×10^{-7}

Behaviour on the whole temperature range is for all samples very similar. The conductance has decreased considerably during irradiation and even heating up to 400 °C does not suppress this effect fully. For practical purposes i.e. electroinsulating the electrodes of the ionic thermometer the properties are improving within required temperature range.

In view of the impossibility to obtain the specific conductance we have for better understanding, calculated the coefficient of conductance decrease k, i.e.

$$k = G_{b.i.}/G_{a.i.} \qquad (3)$$

ratio of conductance before and after irradiation. The actual values are in Table II.

Table II

Conductance decrease induced by irradiation in nuclear reactor described as coefficient K and estimated values of decreased specific conductance

Glass (type)	k	$\varkappa$*) estim. ($S . m^{-1}$)	Glass type	k	$\varkappa$*) estim. ($S . m^{-1}$)
SIMAX	2.47	4.1×10^{-7}	KS-90	2.24	6.6×10^{-6}
SIAL	2.37	3.3×10^{-6}	PN	4.53	2.2×10^{-6}
KS-80	5.51	2.7×10^{-6}	UNIHOST	3.05	9.5×10^{-6}

*) $\varkappa$ — estimated specific conductance ($S . m^{-1}$)

They could be used according to equation (3) to estimate "after-irradiation specific values" from the published specific ones (13). Such estimation is shown for 250 °C in the Table II. The content of boron (decreasing from SIMAX to UNIHOST) has not obviously any influence on decrease of the conductance in spite of considerable energy production and consequently radiation damage from previously mentioned nuclear reaction in the mass of glass.

The possible mechanism of the observed phenomenon is connected probably with the ion diffusion channels disruption by displaced atoms or ions.

The boron heat production

The thermometric measurement in the reactor rig partly equipped by altered thermocouples (Fig. 4) were done at several different levels of the reactor power.

Table III

The average temperature increment caused by heat generation in glasses in dependence on the reactor thermal output

Reactor thermal output, MW	$t_1 - t_2$ °C	$t_{SI} - t_2$ °C	$t_{SU} - t_2$ °C	$t_U - t_2$ °C
0	1.0	—4.0	—1.5	—1.5
7.00	2.5	24.0	21.0	2.0
8.56	3.5	32.0	28.0	4.5
10.00	3.5	35.0	27.5	4.0

Symbols: t_1 — thermometer Fig. 5
t_2 — thermometer Fig. 5
t_{SI} — temperature of SIMAX drop
t_{SU} — temperature of SUPREMAX drop
t_U — temperature of UNIHOST drop

In such way, it was possible to observe the temperature gap between the aluminium cylinder and the glass drop on thermocouple joint. In Table III, the average temperatures increments of the glass drops made out of SIMAX, SUPREMAX and UNIHOST are demonstrated. The PN glass mentioned in the Fig. 5 is omitted, because thermocouple lost its voltage during the experiment. This results were obtained at 350—390 °C at which the CHOUCA-T rig was working (parallel ionic thermometers experiment).
It seems certain, that boron could not be accepted in glasses used for reactor grade ionic thermometers. The found temperature discrepancy between the aluminium holder and thermocouple with glass drops presents the systematic error far too high, to be adjusted by some correction. In finer details, it was possible to find the influence of bad thermal transport between Al-holder and the thermocouples. The heat generation was decreasing with time of the experiment according to increasing burn-out of boron -10 izotope (Table IV).

Table IV

Decrease of heat generation caused by boron-10 burn-out

Reactor thermal output, MW	Runnings hours of the experiment, h	$t_{SI} - t_2$ °C	$t_{SU} - t_2$ °C	$t_U - t_2$ °C
10	24	37.0	33.0	4.5
10	60	35.5	28.5	4.0
10	100	36.0	27.0	4.0
10	140	34.0	25.5	4.0

On the other hand the difference between the thermocouples t_1 and t_2 is very similar to the temperature increase in UNIHOST glass. As a drawback of UNIHOST glass the interference of high sodium content with ionic salt thermometer filling was confirmed.

CONCLUSIONS

The experimental endeavours have shown the possible solution of boron heat generation problem in ionic thermometer design by the application of an boronless glass. As one choice, the use of UNIHOST glass is open, even though it has high sodium content. Its electrical conductance is low enough, especially under irradiation, to ensure good behaviour as an insulator. The burning of ^{10}B izotope is producing considerable temperature increase which could not be simply corrected. The radiation damage in glasses could not be eliminated by heating up to 400 °C, part of conductance paths remained blocked.

ACKNOWLEDGEMENT

Authors would like to dedicate this paper to the memory of RNDr. Miloš B. Volf, CSc., to honour his advices and encouragement.

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ELEKTRICKÉ VLASTNOSTI A CHOVÁNÍ TECHNICKÝCH SKEL V JADERNÉM REAKTORU VVR-S

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Byly ozařovány vzorky skel SIMAX, SIAL, PN, UNIHOST, KS-80, KS-90 v reaktoru VVR-S a studována jejich elektrická vodivost. Byl zjištěn pokles vodivosti po ozáření fluencí tepelných neutronů 2,0 . 10^{23} n . m^{-2}, který je charakteristický pro jednotlivé druhy skel. V reaktorové sondě byla porovnávána generace tepla skel obsahujících bór (SIMAX, SUPREMAX- a bezbórového skla (UNIHOST). Zatímco bezbórové sklo vykázalo přírůstek v mezích chyby měření teploty, obě borosilikátová skla vykázala při teplotách 350—390 °C lokální vzrůst teploty o 39 K, resp. 33 K.

Obr. 1. Obvyklá sestava iontového teploměru;
1 — iontový teploměr, 2 — vodič, 3 — izolační výsyp (MgO), *4 — termočlánkový kabel, 5 — nerezové armování.*
Obr. 2. Skleněná kapka s platinovými elektrodami pro ampulovou ozařovací zkoušku;
1 — skleněná kapka, 2 — platinové elektrody.
Obr. 3. Držák vzorku pro měření elektrické vodivosti při zvýšené teplotě;
1 — čtyřděrová kapilára, 2 — termočlánek, 3 — vzorek, 4 — kelímek z nerezové oceli.
Obr. 4. Úprava armovaného termočlánku pro experiment s generací tepla borem;
1 — termočlánkový spoj, 2 — skleněná kapka, 3 — vzduch, 4 — obálka z nerezové oceli, 5 — termočlánkový kabel.
Obr. 5. Rozmístění termočlánků se skleněnými kapkami v hliníkovém válci reaktorové sondy,
t_1, t^2 — termočlánky, SI — čidlo se sklem SIMAX, SU — čidlo se sklem SUPREMAX, U — čidlo se sklem UNIHOST, PN — čidlo se sklem PN (A. Z. C. — směr k centru aktivní zóny).

ЭЛЕКТРИЧЕСКИЕ СВОЙСТВА И ПОВЕДЕНИЕ ТЕХНИЧЕСКИХ СТЕКОЛ В ЯДЕРНОМ РЕАКТОРЕ ВВР-С

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В реакторе ВВР-С облучались образцы стекол марок СИМАХ, СИАЛ, ПН, УНИГОСТ, КС-80, КС-90 и изучалась их электропроводность. Было установлено снижение проводимости после облучения флюэнсом тепловых нейтронов 2,0 . 10^{-23} нейтр . $м^2$, которое является характеристическим для отдельных типов стекол. В реакторной зонде исследовалось выделение тепла стеклами, содержащими бор (СИМАКС, СУПЕРМАКС), и стеклом без бора (УНИГОСТ). Безборное стекло показало повышение температуры,

сравнимое с ошибкой измерения температуры термопарой. У стекол с бором было отмечено повышение температуры на 39 или соответственно 33 К в области температур 350—390 °C.

Рис. 1. Обыкновенная конструкция ионного термометра: 1 — ионный термометр, 2 — проводник, 3 — изоляционная засыпка (MgO), *4 — термопарный кабель, 5 — армирование из нержавеющей стали.*

Рис. 2. Стеклянная капля с платиновыми электродами для облучения в ампуле: 1 — стеклянная капля, 2 — Pt-электроды.

Рис. 3. Экран-контейнер измерения электропроводности образцов при повышенной температуре: 1 — четырехканальный капиляр, 2 — термопара, 3 — образец, 4 — тигель из нержавеющей стали.

Рис. 4. Вариант армированной термопары для эксперимента с выделением теплоты от ядерной реакции бора: 1 — термопарный рабочий спай, 2 — стеклянная капля, 3 — воздух, 4 — армирование из нержавеющей стали, 5 — термопарный кабель.

Рис. 5. Размещение термопар со стеклянными каплями в алюминиевом цилиндре реакторного зонда: t_1, t_2 *— термопары,* SI *— датчик со стеклом СИМАКС,* SU *— датчик со стеклом СУПЕРМАКС,* U *— датчик со стеклом УНИГОСТ,* PN *— датчик со стеклом ПОЛУБНЫ НОРМАЛ* (A. Z. C. *— направление в центр активной зоны*).

ABRAZÍVNÍ MATERIÁLY (Abrazivnyje materialy). A. P. Garšin, V. M. Gropjanov, J. V. Lagunov. Mašinostrojenije, Leningrad 1983 (232 str., 71 tab., 69 obr.).

Monografie o abrazívních materiálech, která v roce 1983 vyšla v SSSR, se týká velmi aktuální problematiky, související se zvyšováním významu broušení při obrábění kovů, jejich slitin a dalších, především anorganických materiálů. Autoři knihy poprvé, na rozdíl od monografií podobného typu, podávají ucelený výklad základních vlastností abrazívních látek ve vzájemné souvislosti s jejich elektronovou a krystalovou strukturou.

V knize jsou na 232 stranách vysvětleny základy teorie tvrdosti a fyzikálně chemických procesů, které probíhají při syntéze a spékání abrazívních materiálů. Dále jsou popsány teoretické základy rozdružování tvrdých látek. Uváděná technologická schémata výroby brousicích nástrojů a metody modifikování jejich povrchu naznačují možnosti zlepšování užitných charakteristik abrazívních obráběcích nástrojů.

Další pozoruhodností knihy je pohled na ekologické problémy, spojené s výrobou a použitím abrazívních materiálů, především z hlediska spotřeby vody a vodního hospodářství.

S ohledem na všechny výšeuvedené aspekty, které zobecňují a systematizují poznatky o abrazivech na základě současných představ fyziky a chemie pevných látek, je aktuálnost knihy nesporná. Tato monografie bude nejen stimulovat další rozvoj odvětví syntetických velmi tvrdých látek a abrazívních materiálů, ale bude i velmi užitečnou pomůckou pro studenty, technické a inženýrské pracovníky v chemickém, metalurgickém a silikátovém průmyslu, jakož i pro aspiranty a vědecké pracovníky specializované na fyziku a chemii pevných látek.

Vl. Brožek

BERNARD D'ESPAGNAT: IN SEARCH OF REALITY. A PHYSICIST'S VIEW (Hledání reality. Pohled fyzika). Springer Verlag, Berlín 1983. 182 str. cena 16,7 dol.

Kniha pojednává o základní otázce, do jaké míry může současná fyzika potvrdit existenci nezávislé reality mimo naše vědomí. Shromažďuje výsledky posledního vývoje v oblasti fyziky mikročástic a srovnává moderní fyzikální teorie s přístupem několika filozofických škol. Ukazuje, co lze od fyziky očekávat a co naopak fyzika nemůže nikdy odhalit. Autor psal knihu pro čtenáře, kteří se zajímají o filozofické otázky, týkající se základních problémů vědy. Nepoužívá jazyka matematiky, předpokládá však hluboké znalosti o současném vědeckém poznání v oblasti fyziky.

Šatava