AD-A282 462							
Autor of the initial and a second secon	AD-A282	462 ATION F	PAGE	•		Form Approved OMB No. 0704-0	188
Authors ore unit (LEAV DUAL) 2. REPORT DATE UNITY AND SUBTICE Molten Sait Techniques for Excess Heat Production and the Loading Issue The		Die Grand Barris - Street and Str	er response, includio of information. Seni readquarters Service na Budget, Paperno	ng the lime I d comments is, Directorat	or reviewing insi legarding this bu e for informatio Project (0204-01	tructions, searching east wden estimate or any oil n Operations and Report Bill Visibingtion, DC 205	ng days sources. Ner upbers of this , types setters of
THLE AND SUBTILE       Start Techniques for Excess Heat Production and the Loading Issue       Start Techniques for Excess Heat Production         AUTRON(5) Bor Yann LIAW       Contract No. NO014-92-J-1673       Rst Code 4132004srp01         PERFORMING ORGANIZATION HAMI(5) AND ADDRESS(5) Hawaii Natural Energy Institute University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246 Honolulu, HI 95822       DIL 25 1994         JUL 25 1994       F. FERFORMING ORGANIZATION ARVAILABELTY STATION Honolulu, HI 95822       I. SPONSORMIC/MONITORING AGENCY HAMI(5) AND HOMESS(15)       I. SPONSORMIC/MONITORING AGENCY REPORT MUMER BOD North Quincy St. Arlington, VA 22217         32. 003TARBUTION/AVAILABILITY STATIMENT Reproduction in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale; Its distribution is unlimited.       12b. DISTRIBUTION CODE         32. 003TARUTION: ANALABILITY STATIMENT Reproduction has recently been reported, promising great potential for commercial applications. This technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This paper gives an overview of our work in molten salt electrolysis experiment susing Ti and Pd as anodes in deuteride metts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in duver das anodes for electrolysis paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       15         10. SUMICLASSIFIED       10. LIMITED       10. LIMITED	I. MULINLI USC UNLT (LEAVE DIA	(nk) 2. REPORT OATE	3. REPOI	nterim	AND DATES	COVERED	t
Molten Sait Techniques for Excess Heat Production and the Loading Issue       Contract No. N00014-92-J-1673         AUTRORNS: Bor Yann LIAW       Contract No. N00014-92-J-1673         PERIORNING ORGANILATION NAME(S) AND ADDRESS(S)       Contract No. N00014-92-J-1673         PERIORNING ORGANILATION NAME(S) AND ADDRESS(S)       Contract No. N00014-92-J-1673         University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246 Monolulu, H 96822       Sub 251994         SPONSORMC/MONITORING AGINCY NAME(S) AND ADDRESS(S)       Contract No. NOR Technical Report #06         300 North Quincy St. Arlington, VA 22217       P4-232433         1. SUPPLICATION NAMERS       Sub North Quincy St. Arlington, VA 22217         2x DISTRUUTION/AVARILABULY STATEMENT Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.         2x DISTRUUTION/AVARILABULY STATEMENT Reproduction has recently been reported, promising great potential for commercial applications. This technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This paper gives an overview of our work in molten salt electrolysis in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in dydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         10. UNICLASSIFIED	A TITLE AND CURTITLE		_ <u></u>		S. FUNI	DING NUMBERS	$\rightarrow$
AUTHOR(S) Bor Yann LIAW THIORMING ORGANIZATION HAME(S) AND ADDRESS(S) Hawaii Natural Energy Institute University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246 Honolulu, HI 96822 SPONSORMO/MONITORING AGENEY NAME(S) AND KORASS(S) Confice of Naval Research 800 North Quincy St. Arlington, VA 22217 22. DISTANUMENTARY MOTES 23. DISTANUTION/AVAILABULITY STATUMENT Reproduction in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale; its distribution is unlimited. 24. DISTANUTION /AVAILABULITY STATUMENT Reproduction has recently been reported, promising great potential for commercial applications. This technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This spacer also presents some preliminary results using Ni and steel as anodes or electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat productions. 94. 7 22 1 5 1	Molten Salt Techniq and the Loading	ues for Excess Heat Issue	Productio	n	Cont N000	ract No. 14-92-J-1673	
FREMANING ORGANILATION NAME(S) AND ADDRESS(ES)       DITC       A. PERFORMING ORGANILATION         Hawaii Natural Energy Institute University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246       Supersonance       NR Technical Report #06         SPONSORING/MONITORING AGENCY NAME(S) AND NOMESS(ES)       I. SPONSORING/MONITORING AGENCY NAME(S) AND NOMESS(ES)         300 North Quincy St. Arlington, VA 22217       94-23243       IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	8. AUTHOR(S) Bor Yann LIAW			~	R&T 413z	Code 004srp01	
FMORDAMING ORGANIZATION NAME(S) AND ADDRESSIGST       ELECTE         Hawaii Natural Energy Institute       JUL 2 5 1994         University of Hawaii at Manoa       JUL 2 5 1994         JUL 2 5 1994       ONR Technical Report #06         SPONSORING/MONITORING AGENCY NAME(S) AND TORESSIGST       III. SPONSORING/MONITORING CAGENCY NAME(S) AND TORESSIGST         SPONSORING/MONITORING AGENCY NAME(S) AND TORESSIGST       III. SPONSORING/MONITORING AGENCY NAME(S) AND TORESSIGST         SPONSORING/MONITORING AGENCY NAME(S) AND TORESSIGST       III. SPONSORING/MONITORING AGENCY NAME(S) AND TORESSIGST         300 North Quincy St.       Arlington, VA 22217         1. SUPPLEMENTARY NOTES       94-23243         22. DISTRIBUTION/AVAILABILITY STATEMENT       Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale;         1. ASSTRACT (Maximum 200 word)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production							
Hawaii Natural Energy Institute University of Hawaii at Manoa 2580 Dole Street, Holmes Hall 246 Honolulu, H1 95822       SELECTE JUL 25 1994       ONR Technical Report #06         JPONSORING/MONITORING AGENCY NAME(S) AND TODRESS(CS)       I.       ONR Technical Report #06         JPONSORING/MONITORING AGENCY NAME(S) AND TODRESS(CS)       I.       I.       SPONSORING/MONITORING AGENCY REPORT NUMBER         300 North Quincy St. Arlington, VA 22217       94-23243       IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	7. PERFORMING ORGANIZATION I	NAME(S) AND ADDRESS(ES)			8. PERF	ORMING ORGANIZ	ATION
University of Hawaii at Manda JUL 2 5 1994 Honolulu, HI 96822 SPONSORING/MONITORING AGENCY NAME(S) AND PORESS((S) SPONSORING/MONITORING AGENCY NAME(S) AND PORESS((S) SPONSORING/MONITORING AGENCY NAME(S) AND PORESS((S) Arlington, VA 22217 94-23243 SUPPLEMENTAAY NOTES 22. DISTRIBUTION/AVAILABUITY STATEMENT Reproduction in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale; its distribution is unlimited. 2. AdSIMACT (Maximum 200 word) An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions. <b>944</b> 7 <b>222 151</b> <b>15.</b> NUMBER OF PAGES <b>16.</b> ANDER OF PAGES <b>19.</b> ADD THIS PAGE <b>19.</b> CLASSIFIED <b>19.</b> CLASSIFIED	Hawaii Natural Energ	gy Institute	ELECT	E.	REPO		
23-00 Uble Street, Holmes Hail 240       Report Foo         Monolulu, H       96822         3PONSORING/MONITORING AGENCY HAME(S) AND UDRESS(ES)       Io. SPONSORING/MONITORING AGENCY HAME(S) AND UDRESS(ES)         00 North Quincy St.       Arlington, VA 22217         94-23243         1. SUPPLEMENTARY NOTES         12b. DISTRIBUTION / AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale;         12b. DISTRIBUTION / AVAILABILITY STATEMENT         ASTINE THE EXAMPLE Solution is unlimited.         1. Suppletementation in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale;         12b. DISTRIBUTION CODE         ASTINE WIND 200 word!)         ASTINE THE EXAMPLE Solution and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         ASUBILICE TEAMS         IS AUM	University of Hawaii	at Manoa	JUL 2 5 19	994	ONR	Technical	
10. SPONSORING/MONITORING AGENCY NAME(S) AND TUGRESS(ES)       10. SPONSORING/MONITORING AGENCY NAME(S) AND TUGRESS(ES)         0. SPONSORING/MONITORING AGENCY NAME(S) AND TUGRESS(ES)       10. SPONSORING/MONITORING AGENCY REPORT NUMBER         000 North Quincy St.       Arlington, VA 22217         1. SUPPLEMENTARY NOTES       94-23243         12a. DISTRIBUTION/AVAILABULITY STATEMENT       94-23243         Reproduction in whole or in part is permitted for any purpose of the United States Covernment. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. ABSTRACT (Maximum 200 wordi)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride mets, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         15. NUMBER OF PAGES         14. SUBJECT TEAMS         15. NUMBER OF PAGES         15. SECURITY CLASSIFICATION OF ABSTRACT OF THIS PAGE         <td colspan="2</td> <td>Hopolulu HI 96822</td> <td>almes Hall 246</td> <td></td> <td></td> <td>Repo</td> <td>)rt #00</td> <td></td>	Hopolulu HI 96822	almes Hall 246			Repo	)rt #00	
SPONSORING/MONITORING AGENCY NAME(S) AND TORRESS((5)       10. SPONSORING/MONITORING AGENCY NAME(S) AND TORRESS((5)         Office of Naval Research 800 North Quincy St.       94-23243         Arlington, VA 22217       94-23243         I. SUPPLEMENTARY NOTES       12b. DISTRIBUTION/AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale;       12b. DISTRIBUTION CODE         3. ABSTRACT (Maximum 200 wordi)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature excess heat so found. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts. In which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         1. SUBJECT TERMS       15. NUMBER OF PAGES         excess heat, molten salt techniques       15. NUMBER OF PAGES         1. SUBJECT TERMS       18. SECURITY CLASSIFICATION OF ASSTRACT UNCLASSIFIED         1. SUBJECT TERMS       18. SECURITY CLASSIFICATION OF ASSTRACT UNCLASSIFIED	1010101010, 111 50022		C				
Office of Naval Research 800 North Quincy St. Arlington, VA 22217       AGENCY REPORT NUMBER 94-23243         1. SUPPLEMENTARY NOTES       94-23243         22. DISTRIBUTION/AVAILABILITY STATEMENT Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. AdSTRACT (Misimum 200 wordi)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       15         15. NUMBER OF PAGES excess heat, molten salt techniques       15. NUMBER OF PAGES 6 16. PRICE COOE         16. SECURITY CLASSIFICETION UNCLASSIFIED       18. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED       19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	. SPONSORING / MONITORING A	SENCY NAMEISI AND ADDRESSI	ES) .	·····	10. SPO	NSORING / MONITO	RING
800 North Quincy St. Arlington, VA 22217       94-23243         94-23243         1. SUPPLEMENT Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.         A ASTRACT (Maximum 200 wordi)         An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         15. NUMBER OF PAGES 6         - Stounty classification 0/ THIS PAGE         15. NUMBER OF PAGES 6         - Stounty classification 0/ THIS PAGE         15. NUMARE	Office of Naval Rese	arch '			AGE	NCY REPORT NUM	BER
Arlington, VA 22217       94-23243         1. SUPPLEMENTARY NOTES       94-23243         22. DISTRIBUTION/AVAILABILITY STATEMENT       Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         3. ABSTRACT (Maximum 200 words)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         15. SUBJECT TRAMS       15. NUMBER OF PAGES         6       16. PRICE CODE         15. SUBJECT TRAMS       18. SECURITY CLASSIFICATION OF ABSTRACT         16. SECURITY CLASSIFICATION OF THIS PRICE       19. SECURITY CLASSIFICATION OF ABSTRACT         17. SECURITY CLASSIFICED       19. SECURITY CLASSIFICED       10. UMILIMITED <td>800 North Quincy St</td> <td>•</td> <td></td> <td></td> <td></td> <td></td> <td></td>	800 North Quincy St	•					
1. SUPPLEMENTARY NOTES       94-23243         1. SUPPLEMENTARY NOTES       12b. DISTRIBUTION / AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. AdSTRACT (Maximum 200 words)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         4. SUBJECET TEAMS       15. NUMBER OF PAGES         excess heat, molten salt techniques       6         1. SUBJECET TEAMS       15. NUMBER OF PAGES         1. SUBJECET TEAMS       18. SECURITY CLASSIFICATION OF ABSTRACT         1. SUBJECET TEAMS       18. SECURITY CLASSIFICATION OF ABSTRACT         1. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT         1. SECURITY CLASSIFICED       19. SECURITY CLASSIFICED       10. LIMITA	Arlington, VA 2221	7			•		
23. DISTAIBUTION/AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. ABSTRACT (Maximum 200 word))       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       15         15. NUMBER OF PAGES       6         16. FRICE CODE       118. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFICATION OF ABSTRACT UNCLASSIFIED       12. MINITED	_				Q	4-222	12
1. SUPPLEMENTARY NOTES         22. DISTRIBUTION / AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. AdSTRACT (Meximum 200 words)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       1       5         1. SUBJECT TERMS       15. NUMBER OF PAGES         excess heat, molten salt techniques       6         1. SUBJECT TERMS       11. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFICATION OF ABSTRACT UNCLASSIFIED       10. LIMITATION OF ABSTRACT UNCLASSIFIED				<u> </u>	3		TJ.
22. DISTRIBUTION/AVAILABILITY STATEMENT       12b. DISTRIBUTION CODE         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. AdSTRACT (Maximum 200 words)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat so found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94 7 22 151 <sup>1</sup> 15. NUMBER OF PAGES         excess heat, molten salt techniques         15. NUMBER OF PAGES         6         15. NUMBER OF PAGES         6         Recently CLASSIFICATION OF ABSTRACT         UNCLASSIFIED         UNCLASSIFIED         10. SECURITY CLASSIFICATION OF ABSTRACT         10. SECURITY CLASSIFICATION OF ABSTRACT <td>1. SUPPLEMENTARY NOTES</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	1. SUPPLEMENTARY NOTES						
22. DISTRIBUTION/AVAILABILITY STATEMENT       12b. DISTRIBUTION CODE         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.       12b. DISTRIBUTION CODE         2. ABSTRACT (Maximum 200 words)       An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       1       5         Is stocker techniques         Is number of this paper also presents some preliminary results using paper will discuss this aspect and extend to elevated-temperature conditions.         OPA 7       22       1       5         Is number of the production of this paper         Is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         IS SUBJECT TER					110	HAR HAM PERIN MERE UND HAM PE	
22. DISTRIBUTION/AVAILABILITY STATEMENT         Reproduction in whole or in part is permitted for any purpose of the United States Government. This document has been approved for public release and sale; its distribution is unlimited.         22. ABSTRACT (Maximum 200 words)         An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.         94       7       22       1       5         15. NUMBER OF PAGES excess heat, molten salt techniques       15. NUMBER OF PAGES 6         16. PRICE CODE UNCLASSIFICATION OF REPORT UNCLASSIFIED       18. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED       19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED       20. LIMITATION OF ABSTRACT UNCLASSIFIED							
applications. This technique shows improved efficiency due to a high temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions. 94 7 22 151 . SUBJECT TERMS excess heat, molten salt techniques . Stecurity classification of ABSTRACT UNCLASSIFIED UNCLASSIFIED . Mathematical and the stephication of ABSTRACT UNCLASSIFIED . Mathematical aspect and extend to unclassification of ABSTRACT UNCLASSIFIED . SUBJECT TERMS excess heat, molten salt techniques . Stecurity classification of ABSTRACT UNCLASSIFIED . Stecurity classification UNCLASSIFIED . Subject terms . Subj	23. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite	STATEMENT le or in part is permi ed States Government	itted for a	any	12b. Di	TRIBUTION CODE	<u> </u>
1. SUBJECT TERMS       15. NUMBER OF PAGES         excess heat, molten salt techniques       15. NUMBER OF PAGES         6       6         16. PRICE CODE         V. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED       20. LIMITATION OF ABSTRACT UNCLASSIFIED	23. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur 3. ABSTRACT (Maximum 200 wor An interesting molt production has reco	statement le or in part is permi ed States Government approved for public r nlimited. ds) en salt technique for ently been reported, technique shows imp	itted for a . This elease and elevated- promising roved eff	tempe	rature e	Excess heat al for comme a high-temp	ercial
94       7       22       151         I. SUBJECT TERMS         excess heat, molten salt techniques         IS. NUMBER OF PAGES         6         6         15. NUMBER OF PAGES         6         6         16. PRICE CODE         N. SECURITY CLASSIFICATION OF REPORT         OF THIS PAGE         UNCLASSIFIED         UNCLASSIFIED         UNCLASSIFIED	23. DISTRIBUTION/AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur 3. ABSTRACT (Maximum 200 wor An interesting molt production has reco applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss	dstatement de or in part is permited dstates Government approved for public r nlimited. ds) en salt technique for ently been reported, technique shows imp ade heat production a oper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten	elevated- promising roved effi nd fast k w of our in deuter presents n hydride rameter fo d to eleva	tempe great iciency inetics work ide me s some melts or exc ated-te	rature e potenti due to in meta in molter elts, in prelimi . Beca ess heat	Excess heat al for comme al-hydrogen n salt electro which substa nary results use the dete t production are condition	ercial berature olysis antial using rium , this
A. SUBJECT TERMS       15. NUMBER OF PAGES         excess heat, molten salt techniques       6         16. PRICE CODE       16. PRICE CODE         7. SECURITY CLASSIFICATION OF REPORT       18. SECURITY CLASSIFICATION OF THIS PAGE       19. SECURITY CLASSIFICATION OF ABSTRACT       20. LIMITATION OF ABSTRACT         UNCLASSIFIED       UNCLASSIFIED       UNLIMITED	22. DISTRIBUTION/AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur 3. ABSTRACT (Maximum 200 wor An interesting molt production has reco applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss	distantement le or in part is permit ed States Government approved for public r nlimited. ds) en salt technique for ently been reported, technique shows imp ade heat production a aper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fo d to eleva	tempe great iciency inetics work i ide me s some melts or exc ated-te	rature e potenti due to in meta in molter elts, in prelimi . Beca emperatu	excess heat al for comme al-hydrogen n salt electro which substa nary results use the dete t production are condition	ercial berature blysis antial using rium , this us.
excess heat, molten salt techniques          *. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION       16. PRICE CODE         *. SECURITY CLASSIFICATION       18. SECURITY CLASSIFICATION       19. SECURITY CLASSIFICATION       20. LIMITATION OF ABSTRACT         OF REPORT       OF THIS PAGE       OF ABSTRACT       UNCLASSIFIED       UNLIMITED	23. DISTRIBUTION/AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur 3. ABSTRACT (Maximum 200 wor An interesting molt production has recu applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss	distantement statement approved for public r approved for public	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fo d to eleva	tempe great iciency inetics work i ide me s some melts or exc ated-to	rature e potenti due to in meta in molter elts, in prelimi . Beca emperato	excess heat al for comme a high-temp al-hydrogen h salt electro which substanary results use the dete t production are condition	ercial berature olysis antial using rium , this is.
excess heat, molten salt techniques           o         o           16. PRICE CODE         16. PRICE CODE           16. PRICE CODE         18. SECURITY CLASSIFICATION OF ABSTRACT           0F REPORT         0F THIS PAGE           UNCLASSIFIED         UNCLASSIFIED           UNCLASSIFIED         UNCLASSIFIED	A survey will discuss	statement le or in part is permi ed States Government approved for public r nlimited. (5) en salt technique for ently been reported, technique shows imp ade heat production a oper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fi d to eleve	tempe great iciency inetics work i ide me s some melts or exc ated-te	rature e potenti due to in meta in molter elts, in prelimi Beca emperatu	excess heat al for comme a high-temp al-hydrogen n salt electro which substa nary results use the dete t production are condition	ercial berature olysis antial using rium , this is.
7. SECURITY CLASSIFICATION 18. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 20. LIMITATION OF ABSTRAC OF REPORT OF THIS PAGE OF ABSTRACT UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED UNLIMITED	222. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur 3. ABSTRACT (Maximum 200 wor An interesting molt production has reco applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss 4. SUBJECT TERMS	statement le or in part is permi ed States Government approved for public r nlimited. (5) en salt technique for ently been reported, technique shows imp ade heat production a oper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fi d to eleve	tempe great iciency inetics work i ide me s some melts or exc ated-to	12b. 019 rature e potenti due to in meta in molter elts, in prelimi . Beca emperatu	excess heat al for comme a high-temp al-hydrogen n salt electro which substanary results use the dete t production are condition <b>15.</b> NUMBER OF	ercial berature olysis antial using rium , this is.
OF REPORT OF THIS PAGE OF ABSTRACT UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED UNLIMITED	<ul> <li>23. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur</li> <li>3. ABSTRACT (Maximum 200 wor An interesting molt production has reco applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss</li> <li>4. SUBJECT TERMS excess heat, molten</li> </ul>	salt techniques	elevated- promising roved effi nd fast k w of our in deuter presents n hydride rameter fo d to eleva	tempe great iciency inetics work i ide me s some melts or exc ated-to	rature e potenti due to in meta n molter lts, in prelimi Beca emperatu	EXCESS heat al for comme a high-temp al-hydrogen h salt electro which substa nary results use the dete t production are condition 15. NUMBER OF 6 16. PRICE CODE	ercial berature olysis antial using rium , this is. PAGES
UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED UNLIMITED	<ul> <li>222. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is ur</li> <li>ABSTRACT (Maximum 200 wor An interesting molt production has recu applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss</li> <li>4. SUBJECT TERMS excess heat, molten</li> <li>7. SECURITY CLASSIFICATION 1</li> </ul>	STATEMENT le or in part is permi ed States Government approved for public r nlimited. ds) en salt technique for ently been reported, technique shows imp ade heat production a aper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten salt techniques	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fi d to eleva	tempe great iciency inetics work i ide me s some melts or exc ated-to	12b. Dis rature e potenti due to in molter lts, in prelimi Beca emperatu 222	EXCESS heat al for comme a high-temp al-hydrogen n salt electro which substa nary results use the dete t production are condition 15. NUMBER OF 6 16. PRICE CODE	ercial berature olysis antial using rium , this is. PAGES
	<ul> <li>222. DISTRIBUTION / AVAILABILITY Reproduction in who purpose of the Unite document has been a its distribution is un</li> <li>23. ABSTRACT (Maximum 200 wor An interesting molt production has reco applications. This operation, high-gra reactions. This pa experiments using excess heat was for Ni and steel as and loading in Pd is co paper will discuss</li> <li>4. SUBJECT TERMS excess heat, molten</li> <li>7. SECURITY CLASSIFICATION OF REPORT</li> </ul>	statement le or in part is permi ed States Government approved for public r nlimited. (6) en salt technique for ently been reported, technique shows imp ade heat production a oper gives an overvie Ti and Pd as anodes und. This paper also odes for electrolysis i nsidered a critical pa this aspect and exten salt techniques	elevated- promising roved effi nd fast k w of our in deuter o presents n hydride rameter fi d to eleva 94	tempe great iciency inetics work i ide me some melts or exc ated-te TY CLASS	12b. Dis rature e potenti due to in meta in molter elts, in prelimi . Beca emperatu 22	EXCESS heat al for comme a high-temp al-hydrogen n salt electro which substa nary results use the dete t production are condition 15. NUMBER OF 6 16. PRICE CODE	ercial berature olysis antial using rium , this is. <b>1</b> PAGES DF ABSTRAC

.

### OFFICE OF NAVAL RESEARCH

GRANT: N00014-92-J-1673

R&T Code: 413z004srp01

Technical Report No. 06

# Molten Salt Techniques for Excess Heat Production and the Loading Issue

by

Bor Yann Liaw

Prepared for Publication

in the

Proceedings of the Minsk International Cold Fusion and Energy Conference May 24-26, 1994, Minsk, Belarus

> Hawaii Natural Energy Institute School of Ocean and Earth Science and Technology University of Hawaii at Manoa 2540 Dole Street, Holmes 246 Honolulu, HI 96822

> > July 12, 1994

Production in whole or in part is permitted for any purpose of the United States Government.

This document has been approved for public release and sale; its distribution is unlimited. Minsk International Cold Fusion and Energy Conference May 24-26, 1994, Minsk, Belarus

### MOLTEN SALT TECHNIQUES FOR EXCESS HEAT PRODUCTION AND THE LOADING ISSUE

Bor Yann Liaw Hawaii Natural Energy Institute School of Ocean and Earth Science and Technology University of Hawaii at Manoa 2540 Dole Street, Holmes Hall 246 Honolulu, HI 96822, USA

#### ABSTRACT

An interesting molten salt technique for elevated-temperature excess heat production has recently been reported, promising great potential for commercial applications. This technique shows improved efficiency due to a high-temperature operation, high-grade heat production and fast kinetics in metal-hydrogen reactions. This paper gives an overview of our work in molten salt electrolysis experiments using Ti and Pd as anodes in deuteride melts, in which substantial excess heat was found. This paper also presents some preliminary results using Ni and steel as anodes for electrolysis in hydride melts. Because the deuterium loading in Pd is considered a critical parameter for excess heat production, this paper will discuss this aspect and extend to elevated-temperature conditions.

#### THE MOLTEN SALT TECHNIQUES

#### **Deuteride-Based Systems**

Since the announcement of the Fleischmann-Pons effect in 1989, a team led by Liebert and Liaw has been working on a project using the molten salt techniques to verify such an effect. Earlier experiments in 1989 involved the electrolysis of Ti and Pd anodes in LiD-containing melts [1,2], in which commercially available Al alloys were used as the cathode . Operating at about 400°C, these molten salt cells produced excess power, ranging from 30% in the Ti-D system to more than 600% in the Pd-D system. No excess power or heat has ever been measured in analogous experiments using LiH-containing melts. However, replication of the excess heat effect in the Pd-D system has been difficult due to several problems, including chloride formations involving various electrodes and lead materials under a starving LiH(D) condition in the melts and severe cracking and disintegration from uncontrollable sample preparations and uneven charging conditions associated with the Pd electrodes.

Molten salt techniques provide an interesting alternative to the aqueous electrolysis methods for excess heat production, although the degree of control of these techniques need to be improved. Typical molten salt electrolytes used in our experiments are eutectic LiCl-KCl melts saturated with excess LiH(D). This electrolyte system has a melting point of 350°C and has a very high ionic conductivity of the order of 1  $\Omega$ -1 cm<sup>-1</sup>, higher than any other proton-based conductors at these temperatures. The presence of LiH(D) in the melts introduces a very reducing environment, in which most transition metal oxides become unstable. This unique property provides an effective method of removing metal surface oxides in situ, resulting in "hydrogen-transpar-

ent" metal surfaces which facilitate the metal-hydrogen reactions. This technique is particularly useful for transition metals such as Ti, Zr, V, Ta, and their alloys, whose potential for excess heat production might be attractive due to their high solubility of hydrogen and deuterium.

The molten salt techniques are based on the electrolysis of LiH(D) through hydrogen-transparent surfaces to charge H or D into metal anodes and produce excess heat with enhanced kinetics and efficiency. Several interesting results were found in our successful excess-heat-producing Pd-D experiments:

- The excess power level, of the order of 9-25 W, was 6-15 times, or 600-1,500%, larger than
  the input electrochemical power (~0.6-1.7 W, depending on current density) with no
  consideration of thermoneutral potentials. The excess power was a linear function of
  current density. The excess heat was of the order of 6-7 MJ mol<sup>-1</sup> D<sub>2</sub>, significantly larger
  than any known chemical reaction enthalpies. Figure 1 shows the input and output
  power excursion profiles at different current densities in this particular experiment.
- The total excess heat was of the order of 5 MJ, at a rate of about 9-25 W for 4 days. This
  magnitude of excess power is difficult to be explained by any storage mechanisms,
  contaminations or other artifacts.
- Four specimens from the spent Pd electrode have been analyzed by high-precision mass spectroscopy to quantify their residual He-4 content. All of them have shown enhanced He-4 content above the level of the background or a control Pd blank [3]. Although the amount of excess He-4 was not commensurate with the magnitude of excess heat, the increased He-4 content was a surprise to us since a similar H-based experiment showed an opposite result. Figure 2 shows the He-4 enhancement in the Pd specimens versus those of the background and the virgin electrode used as a control.



Figure 1. The power excursion curves of the inputs and outputs during a charging experiment using a Pd anode and an Al alloy cathode in a D-melt. Charging current densities are indicated. For detailed experimental parameters, please refer to refs. 1 and 2.

Figure 2. He-4 analysis results of the spent Pd anode and a control sample. All four specimens of the anode show increased He-4 content, although the amount was not commensurate with the excess heat measured.

### **Electrochemical Characterization**

Because of the irreproducibility of the molten salt techniques, substantial effort has been made to study the electrochemical behavior of the electrodes in the molten salt system. Cyclic voltammetry technique and polarization studies [4,5] were conducted in the H-containing melts using various anode materials, including Pd, W, Mo, Al and Ni. These studies have led to the understanding of the effect from impurities such as Si, which acts as an inhibitor to the hydrogen evolution reaction. The results also indicate the LiH concentration can alter electrochemical behaviors and reaction paths. When LiH concentration is low, increased chloride activity can promote the metal chloride formation that corrodes the electrode and the lead, leading to the failure of cell operation. It is important to control the type of impurity present in the melt and its concentration to facilitate the Pd-hydride formation, thus enhancing the loading.

### Hydride-Based Systems

These electrochemical studies also led to a more recent calorimetric investigation of the Ni-H system in the molten salt [6], in which excess power was measured, similar to those reported by several groups using carbonate-electrolyte light-water electrolysis and Ni cathodes at ambient temperature. Preliminary results showed that some low level of excess power was measured during the galvanostatic charging process with different current densities. The excess power (~0.5 W) was of the order of 30-100% of the input power. If we take the thermoneutral potential from various possible cell reactions into consideration, the gain of the excess power was even higher, of the order of several hundred per cent. Although the Ni-H experiments seem quite reproducible, the magnitude of the excess power however is low, unlike the Pd-D results. The origin of the excess power in this Ni-H case is unknown and may be caused by side reactions or other artifacts, which need to be investigated further. However, in a similar electrolysis using steel as the anode showed no excess power.

## THE LOADING ISSUE

It has been demonstrated in low-temperature heavy-water electrolysis experiments [7,8] that a threshold loading ratio of about 0.84 is essential for excess heat production. In all molten salt experiments so far, we have not been able to report the loading ratio related to the calorimetric measurements. It is inherently difficult in our elevated-temperature experiments, particularly in situ, to measure the loading ratio. The resistivity ratio  $(\mathbb{R}/\mathbb{R}^{\circ})$  and gas volumetric techniques are two methods often used to measure the loading ratio in ambient-temperature experiments. The gas volumetric technique has recently been adopted by Okamoto and Nezu [9] at the IMRA Material R&D, Japan, to measure the loading ratio of H in Pd in the molten salt environments. They reported a very shallow loading, similar to what would be expected from the equilibrium phase diagram, in their Pd samples from electrochemical charging. Their cyclic voltammetry results, however, showed a series of anodic and cathodic peaks, guite different from what we have reported [3,4], indicating a very complicated environment in their electrolyte systems. According to the phase diagram reported by Levine and Weale [10] and the overpotentials often measured in our cells (~0.6-1.0 V), we can estimate the fugacity of the Pd anode to be about 10<sup>10</sup>-10<sup>15</sup> atm. The relationship of pressure and fugacity reported by Baranowski and Wisniewski [11] can then be used to extrapolate the loading ratio during an effective charging. A range of D/Pd>0.7 is thus obtained, which is quite different from those reported by Okamoto and Nezu.

The gas volumetric technique is less sensitive than the  $R/R^{\circ}$  technique for time-dependent loading measurements in a dynamic charging situation. Nevertheless, reliable data between the  $R/R^{\circ}$  and the loading ratio at elevated temperatures have not been established experimentally. The  $R/R^{\circ}$  technique is difficult to be used in the molten salt environment due to the lack of a suitable insulating material in order to confine the cell geometry. In addition, the high conductivity of the melt makes the parasitic resistance of the electrolyte comparable to that of the electrode hence increases the difficulty of an accurate measurement. Despite these problems, the loading ratio is still an important parameter to be characterized for better control of the excess heat effect.

The issue of the threshold loading for observing anomalous excess heat effect is an interesting open question for both ambient and elevated temperatures. Although the necessity of such a threshold loading at elevated temperatures has not yet been demonstrated or verified experimentally, there is a consensus in this field that such a threshold loading should exist.

The underlying mechanism dictating how the threshold loading control the excess heat effect has not been revealed yet. The meaning of  $R/R^{\circ}$  and its relationship to this threshold loading have not been discussed in great details, either. On the other hand, experimental evidence shows that  $R/R^{\circ}$  could vary with the state of the electrode to some extent associated with the electrode preparation, heat treatment, history, and other metallurgical and material aspects such as microstructure and morphology, defect type and concentration, magnification and interaction of defects, stress state and distribution, etc. However, how well are these factors related to the origin of the excess heat should provide important clues to our understanding of the excess heat phenomenon. To seek such links, we have to carefully investigate these factors and their effect on the loading issue.

The threshold loading of D/Pd=0.84 at room temperature did not coincide with the crystallographically-ideal, saturated composition of D/Pd=1, of which deuterium will occupy all the octahedral sites in the lattice. This threshold loading did not coincide with the maximum of the R/R° curve at D/Pd=0.72, either. More recently, the possibility of a new  $\gamma$ -hydride phase was proposed. The structure of this phase has not been reported yet. It could be associated with tetrahedral-site occupancy. It could also be associated with a lattice distortion in which octahedral sites were distorted into a different symmetry due to partial site occupancy of deuterium. It could also come from a disordered-ordered lattice transition with preferred site occupancy. If the structure is anisotropic, it could exhibit a Jahn-Teller effect. This phase, if it exists, should be considered metastable, to only occur under certain extreme, non-equilibrium conditions.

In the case of elevated temperatures such as 400°C, according to the phase diagram of the Pd-H(D) system, it is difficult to conceive how a loading ratio of over 0.8 can be achieved through gas loading unless an extremely high hydrogen pressure was applied. The pressure-concentration-temperature (p-c-T) curves of the system indicate that the H(D) concentration in Pd decreases with temperature under an isobaric condition. The equilibrium H(D) concentration in Pd is rather low (<0.1) at low ambient pressures (<30 atm) and high operating temperatures such as 400°C. On the other hand, electrolysis is a dynamic situation which could be different from the equilibrium condition significantly. It is generally believed that electrochemically charging can achieve conditions beyond those from gas loading. If we believe the threshold loading is related to excess heat production through some crystal structure changes and/or defect interactions, it would be beneficial to consider the loading from a thermodynamic point of view to reveal more insightful aspects of the defect chemistry involved.

It is well known that crystal defect structure and interaction strongly affect the p-c-T characteristics. Wagner [12] has shown, from thermodynamic principles, the significance of the curvature of the p-c-T curves, or, in electrochemical sense, the coulometric titration curves in terms of stoichiometry of a solid compound, which is readily attainable from the following analysis:

Consider the compound  $PdH_{\beta+\delta}$  involving H atoms in interstitial sites (H<sub>i</sub>) of the Pd lattice and their vacancies (V<sub>H</sub>) as the essential point defects, as described by a Frenkel disorder model. The excess H is the difference between the mole fractions of H<sub>i</sub> and V<sub>H</sub>,

$$\delta = X(H_i) - X(V_H), \tag{1}$$

where  $X(H_i)$  equals to the loading ratio, and PdH<sub>β</sub> is presumably the stoichiometric composition of the hydride phase at a particular temperature. When the defect concentrations are low, interaction among defects may be neglected. We can then assume that

$$X(H_i) \approx a_{H_i}$$
 and (2)

$$X(V_H) \approx a_H^{-1} \tag{3}$$

For the stoichiometric composition PdH<sub>B</sub>, where  $\delta = 0$ ,

$$X^{\circ}(\mathbf{H}_{i}) = X^{\circ}(\mathbf{V}_{H}). \tag{4}$$

We can rewrite

$$X(\mathbf{H}_i) = X^{\circ}(\mathbf{H}_i)(\mathbf{a}_H/\mathbf{a}^{\circ}_H), \text{ and}$$
(5)

$$X(V_H) = X^{\circ}(H_i)(a_H/a^{\circ}_H)^{-1}.$$
 (6)

Substituting (5) and (6) in (1), we obtain

$$\delta = X^{\circ}(H_i)[(a_H/a^{\circ}_H) - (a_H/a^{\circ}_H)^{-1}] = 2X^{\circ}(H_i)\sinh[\ln(a_H/a^{\circ}_H)].$$
(7)

A plot of  $\ln(a_H/a^\circ_H)$  versus  $\delta$  yields an antisymmetric curve with an inflection point at the ideal stoichiometric composition. We can thus determine the stoichiometric point for a solid phase at the inflection point of the coulometric titration curve. This behavior applies to the p-c-T curves of the Pd-H system at high temperatures above the 300°C critical point, and, indeed, distinct inflection points are identifiable. Thus, at 400°C, the stoichiometric point is at about H/Pd=0.38, according to the p-c-T curves reported by Levine and Weale [10].

Below the critical point, where the  $\alpha$ - $\beta$  miscibility gap presents, the p-c-T curve in the  $\beta$ -phase region is concave above the phase boundary (H/Pd>0.59 at 25°C) [13]. Neutron diffraction measurement, however, indicated that the hydrogen occupies the octahedral sites in Pd, thus leading to the belief that, at saturation, H/Pd=1 is the stoichiometric composition of the  $\beta$ -phase. There is no indication if the p-c-T curve turns convex and an inflection point exists that represents the stoichiometry as described above. Therefore, it seems that the defect chemistry may be different at low and high temperatures. Despite the difference, how the defect chemistry play the role to the maximum (H/Pd=0.72) of the R/R° versus loading ratio curve and the threshold loading (D/Pd=0.84) for the anomalous excess heat effect is an intriguing subject for future studies.

#### CONCLUSION

The molten salt technique is a unique approach to excess heat production at elevated temperatures, promising high grade heat and improved efficiency. Both the Pd-D and Ni-H systems were investigated, and excess power was observed, although the origin of these anomalies were not identified. The electrochemical behavior of the molten salt system is complicated by the presence of impurities. Control of the electrode material property and the impurities are critical for reproducibility. Although demonstration of a threshold loading to the excess heat effect in elevated-temperature electrolysis is lacking, the importance of this parameter is speculated. We are interested in investigating the temperature-dependent relationships among the stoichiometric composition of the hydride phase, the loading of the maximum R/R° value and the threshold loading of the excess heat effect. The correlation of these three loading values with the underlying defect chemistry may reveal some important crystal structure variations and associated defect interactions that may be related to the excess heat phenomenon.

#### ACKNOWLEDGEMENT

This work has been supported by the University of Hawaii, U. S. Office of Naval Research, and Fusion Resources, Inc./ENECO. I would also like to acknowledge the contributions from my colleagues, Professor Bruce E. Liebert, Dr. Robert A. Huggins, Dr. Debra R. Rolison, Dr. Robert J. Nowak, Dr. Talbot Chubb, and many others.

#### REFERENCES

- 1. B. Y. Liaw, et al., in the Proceedings of the Symposium on "Cold Fusion," the 8th World Hydrogen Energy Conference, Honolulu/Waikoloa, Hawaii, July 22-27, 1990, p. 49.
- 2. B. Y. Liaw, et al., J. Electroanal. Chem. 319 (1991) 161.
- 3. B. Y. Liaw, et al., Fusion Tech. 23 (1993) 92.
- 4. B. Y. Liaw and B. E. Liebert, Proc. of the 8th Internat. Symp. on "Molten Salts," ed. R. J. Gale, G. Blomgren and H. Hojima, Electrochem. Soc., PV 92-16, p. 1.
- 5. B. Y. Liaw and Y. Ding, to be published in Solid State Ionics.
- 6. B. Y. Liaw and Y. Ding, to be published in Proc. ICCF-4, Maui, Hawaii, Dec. 6-9, 1993.
- 7. M. C. H. McKubre, et al., in Frontiers of Cold Fusion, ed. H. Ikegami, Universal Academy Press, Inc., Tokyo, p. 5.
- 8. K. Kunimatsu, et al., in Frontiers of Cold Fusion, ed. H. Ikegami, Universal Academy Press, Inc., Tokyo, p. 31.
- 9. H. Okamoto and S. Nezu, to be published in Proc. ICCF-4, Maui, Hawaii, Dec. 6-9, 1993.
- 10. P. L. Levine and K. E. Weale, J. Chem. Soc. Faraday Trans. 56 (1960) 357.
- 11. B. Baranowski and R. Wisniewski, Phys. Stat. Sol. 35 (1969) 593.
- 12. C. Wagner, in Progress in Solid State Chemistry, Vol. 6, ed. Reiss and McCaldin, Pergamon Press, Oxford, 1971, p. 1.
- 13. J. R. Lacher, Proc. Roy. Soc. 161 (1937) 525.