

A REVIEW OF CANADIAN DEVELOPMENTS ON HYDROGEN PRODUCTION PROCESSES SUITED FOR SMALL NUCLEAR REACTORS

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ABSTRACT – Canada is developing the Copper-Chloride process and High Temperature Steam Electrolysis for hydrogen production through integration with current and future nuclear reactor technologies. Successful innovations are achieved through collaborations.

1. Introduction

Hydrogen is a very valuable commodity even at its current national and world-wide demands. Its demand is growing rapidly due to the increasing population of the world and the consequent demand for energy and manufactured products. Also, low-grade and/or other types of oil resources, considered to be uneconomical for commercial utilization at one time, are being exploited to meet the increasing world demand, necessitating an increased use of hydrogen for upgrading. Current hydrogen production processes emit an enormous amount of greenhouse gases, negatively impacting the environment. Hence, there is a clear need for hydrogen production processes that are environmentally greener.

2. Copper-Chloride Cycle

Thermochemical hydrogen production processes are inherently more efficient due to the high temperatures that they operate at. Many countries are involved in developing different processes depending on the type of nuclear reactor that they have selected as their next generation or for Small Modular reactor technologies. Canada has chosen Super Critical Water Reactor (SCWR) as its Generation IV nuclear technology. Because of its moderate temperature operation (maximum 625°C), only a limited number of hydrogen production processes can be integrated with it. The Copper-Chloride process, shown in Figure 1, is well suited for large-scale or Small Modular SCWR concepts.

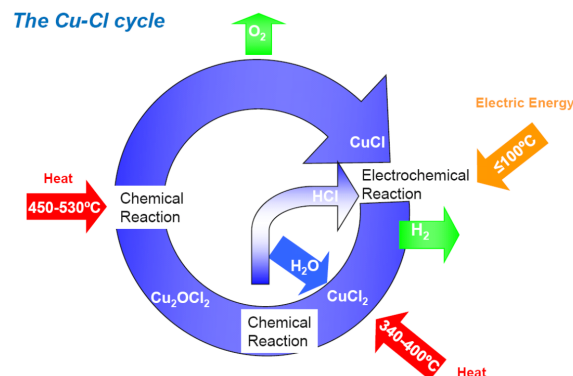


Figure 1 Copper-Chloride Cycle

A set of four main steps, shown in Table 1, characterize this hydrogen production process. The maximum temperature requirement of the process is for the thermal decomposition step (Step 4 in Table 1) which can be easily met by the Canadian SCWR concept. Because of its moderate temperature requirements, the Copper-Chloride process is easier to integrate with solar energy.

Table 1 Main steps of the Copper-Chloride Process

Step		Reaction	Temperature range (°C)
1	Electrolysis	$2\text{CuCl}_{(g)} + 2\text{HCl}_{(g)} \rightarrow 2\text{CuCl}_{2(aq)} + \text{H}_{2(g)}$	~100
2	Separation/drying	$\text{CuCl}_{2(aq)} \rightarrow \text{CuCl}_{2(s)}$	<100
3	Hydrolysis	$2\text{CuCl}_{2(s)} + \text{H}_2\text{O}_{(g)} \rightarrow \text{CuO} \cdot \text{CuCl}_{2(g)} + 2\text{HCl}_{(g)}$	350-400
4	Thermal	$\text{CuO} \cdot \text{CuCl}_{2(s)} \rightarrow 2\text{CuCl}_{(l)} + 1/2\text{O}_{2(g)}$	450-530

As part of the International Nuclear Energy Research Initiative (INERI) and Generation IV International Forum (GIF), A Canadian network consisting of many universities led by the University of Ontario Institute of Technology (UOIT), AECL and Argonne National Laboratory (ANL) is developing the overall process with the objective of integrating all the steps of the process for pilot plant demonstration (Figure 2) at UOIT's Clean Energy Research Laboratory (CERL) in Oshawa [2].

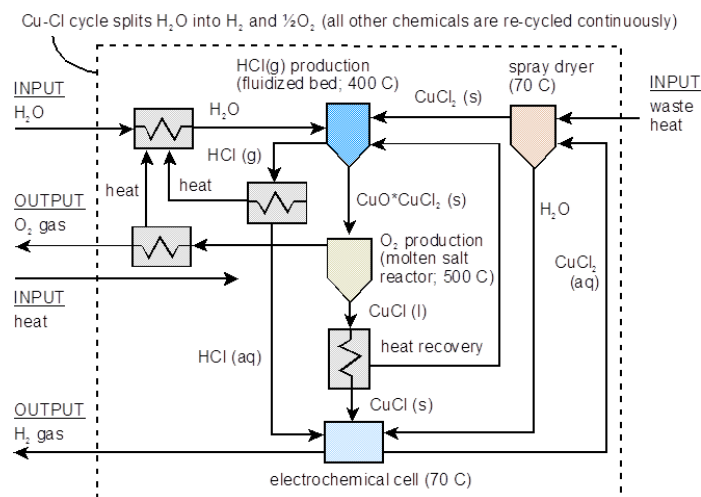


Figure 2 Simplified schematic of Copper-Chloride Cycle as presented by [1]

3. High Temperature Steam Electrolysis

As with thermochemical processes, electrolysis of steam at high temperatures is an efficient method to produce hydrogen. As part of INERI, AECL collaborated with Idaho National Laboratory (INL) to demonstrate the feasibility of integrating High Temperature Steam Electrolysis (HTSE) with current and future Canadian Nuclear Reactor technologies [3].

Though successful short-term operations of different cell designs have been amply demonstrated by INL and other international organizations, long term operations of the cells have shown material issues with the various components of the cells. These high temperature-related issues may be minimized if the temperature of operation can be reduced, even marginally, from the current range of 800 to 900°C. Such a reduction in the operating temperature will also help increase the overall efficiency of hydrogen production through integration with Canada's SCWR concept. Hence, AECL is leading an effort in collaboration with industrial partners to demonstrate long-term performance of the electrolyser at temperatures in the range of 650 to 800°C.

4. Conclusions

Canada's effort in the application of nuclear energy for hydrogen production is focused on the moderate-temperature thermochemical cycle, Copper-Chloride, and steam electrolysis. The collaboration among Canadian universities, AECL and ANL has produced a number of very successful innovations in the development of the Copper-Chloride Cycle.

Integration of the HTSE with current Canadian nuclear reactors or future concepts has also been shown to be feasible. Material developments are underway in Canada for successful long-term operation of steam electrolyzers.

5. References

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- [2] Naterer G.F., S. Suppiah, L. Stolberg L, M. Lewis, Z. Wang Z, V. Daggupati V, et al., Canada's program on nuclear hydrogen production and the thermochemical Cu-Cl cycle, International Journal of Hydrogen Energy, **35**, p 10905-26, 2010.
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