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How does chemistry of rare earth metals coordination complexes can enhance system thinking ability? A qualitative content analysis study

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Abstract

Chemistry of rare earth metals coordination complexes has a potential as a material for teaching and learning sustainable chemistry principles. System thinking has an important role to link the chemistry of rare earth metals coordination complexes to the principle of sustainability. This study was conducted to obtain scientist conception about chemistry of rare earth metals coordination complexes as sustainable material that emphasized enhancement students' system thinking ability. The Method used is qualitative content analysis (inductive literature review type). It is includes the collection of research articles, descriptive analysis, category selection and material evaluation based on didactical view. The instrument used is a content analysis format related to the concept of rare earth metals coordination complexes. The results showed that the scientist's conception of rare earth metals coordination complexes can be analyzed to qualitative with used inductive approach. The scientist's conception was obtained which are important concepts such as synthesis, characterization, and application of material based on rare earth metals. The synthesis of coordination complexes is carried out using central atoms in the form of metals and/or rare earth ions with several ligands. The characterization of complexes compound conducted to determine their solubility, crystal structure, and physicochemical properties. Based on its application reviewed, chemistry of coordination complexes showed environmentally safe properties, society, and increase economic value.

Keywords: *Chemistry of coordination complexes, Rare earth metals, Sustainability, System thinking.*

1. Introduction

System thinking had been attented to chemistry educators in recent years [1, 2]. The current research trend refers to the SDGs United Nations Program to encourage all of disciplines to be oriented towards the principle of sustainability. The purpose of this study to investigated the characteristics of rare earth metal complex compounds that have the potential as sustainable compounds by optimizing systems thinking. Chemistry has a strategic role in linking all relevant disciplines with the principles of sustainable living in environmental, social, and economic aspects [3]. Chemistry can be linked to the principle of sustainable living through system thinking. In Studying of chemistry concept, it is not understanding the concept, but it is important to associate between chemical concepts into a unitary conceptual system. Chemical activity is indicated by the product of the system thinking that is used to predict which material products have the potential for sustainable materials. Unfortunately, research into system thinking in chemistry learning is still rarely carried out at this time. It is challenge for chemistry educators to take steps in the practice of learning chemistry by integrating sustainable molecular principles [4].

The Novelty of this studies were (1) the chemistry of rare earth metal complexes coordination has a molecular basis of sustainability. (2) the ability to system thinking in guiding interdisciplinary into the chemistry of rare earth metals coordination complexes by paying attention to the principle of sustainability. Several studies in the field of chemistry education that have been started to apply the systems thinking approach, are still being carried out on elemental chemistry. There was not research on complex coordination chemistry learning that applied students' system thinking skill. The application of system thinking in the field of chemistry is directed to provide students with understanding of connecting between concepts, analysis, synthesis chemical products, but has not yet paid attention to the basic of molecular sustainability principles [5]. Therefore system thinking has an important role for students in studying coordination complex compounds that are based on the principle of molecular sustainability [4].

Coordination complex compounds have been widely investigated through various stages of reactions using metal ions and various ligands. Research on the synthesis of coordination complex compounds has been carried out without paying attention to the sustainable aspect [6]. The applications of coordination complex compounds is very diverse and as a research on coordination complexes continues to evolve in line with the development of science and technology. One of the advances in the chemistry of coordination complexes is the application of Rare Earth Metals as central atoms covalently bonded with ligands that can form coordination complexes. In general, rare earth metals is magnetic, therefore in the application of its complex compounds it is expected to be a product that is a strong permanent magnet [5, 6]. The difference in electrons that can be fully or half filled is due to the splitting of energy in the d orbitals, causing a magnetic force.

An important role in understanding the basic concept of sustainability at the molecular level (molecular level of sustainability) is needed as a basic for thinking that connects the chemistry of rare earth metals coordination complexes concept with the principle of sustainability in the environmental, social, and economic aspects in life. However, the systems perspective in linking chemical activity to sustainability challenges is not yet fully systematically embedded in chemical practice. Therefore, chemistry education students need a systematic frame of thinking in describing a way to link knowledge of molecular science with the principle of sustainability of the earth as its social life. This is a challenge for chemistry educators in providing to problems solving and critical thinking by creating chemical products with sustainability principles [7, 8]. Based on this global issue, it is important to analyze previous studies related to the chemistry of rare earth coordination complexes that have the potential for the development of life in the environmental, social, and economic aspects. This qualitative content analysis encourages to strengthen students' systems thinking skills in studying chemistry for sustainability.

2. Materials and methods

The method used was qualitative content analysis (inductive literature review type) [9]. The first stage is carried out by collecting research articles. The material collected is adjusted to the topic under study and limited to its time dimension and relevance. The second stage is descriptive analysis, this stage provides an overview of the background of the literature analysis carried out. The third stage is category selection and material evaluation based on didactic views. The fourth stage is interpreting the results of the analysis. In the inductive approach, definitions and coding for each category can be developed after the material is analyzed. The instrument used was a content analysis form related to chemistry of rare earth coordination complexes.

In the material analysis step, there is a cycle that describes a detailed explanation. Figure 1 show how the feedback process in material analysis is appropriate.

Figure 1. The research process of the structure of content analysis [9]

2.1. Material Collection

Collecting material that is relevant to the theme of the study and is limited based on certain criteria. The material collected is material that is often used as reference material.

2.2. Search for Related Papers

Searching for scientific literatures that contains a clear conceptual, among the materials that have been collected.

2.3. Descriptive Analysis

Describe the formal aspects of the material that has been studied, such as the background, research methodology or research results.

2.4. Category Selection

Categorization was chosen for the initial arrangement of important concepts in content analysis. The selected category has a field of study that is related to other main fields.

2.5. Interpreting Results of the Literature Review

The material is analyzed and selected based on the predetermined structural dimensions and categorization. The interpretation of the results is able to identify research gaps. At the stage of determining the category (coding) in the material analysis step, it is carried out through three (3) phases, as shown in Figure 2. Organizing the analysis into the first category (phase 1), generalizing a number of categories (phase 2), rejecting a number of irrelevant categories (phase 3).

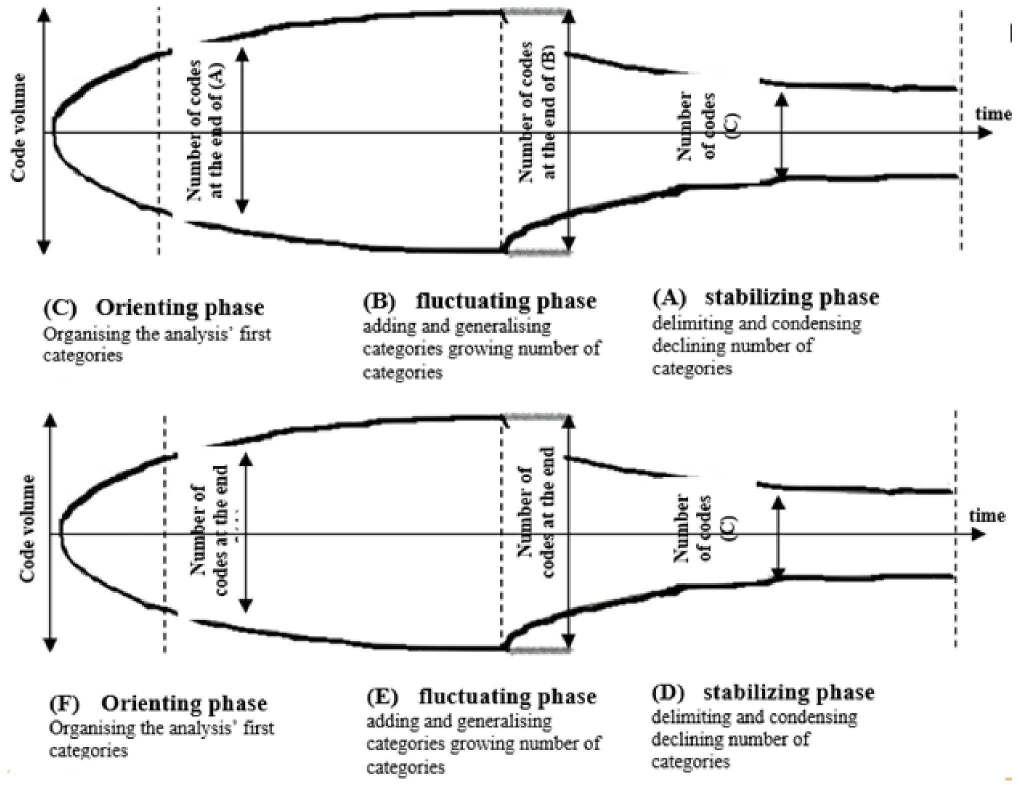

Figure 2. Three steps in the coding process

3. Result and Discussion

3.1. The results of the qualitative content analysis

Literature search is carried out using the help of PoP (Publish or Perish) software by determining the keywords that most frequently appear 'Chemistry of Rare Earth Coordination Complexes'. In the initial search, a total of 137 articles, 3 book chapters and 3 monographs were obtained through the google scholar database from different years of publication. Furthermore, the search was narrowed by taking the most frequently occurring articles based on citation, characterization relevance and application to the complex chemistry of rare earth coordination complexes [10]. The selected literature represents a more limited number of articles, book chapters and monographs as showed in Table 1. The limitation of literature aims to focus more on analyzing content qualitatively on predetermined topics.

Table 1. Comparison metrics

Metrics Data	Initial search	Refinement search
Source	'Chemistry of Rare Earth Coordination Complexes'	'Chemistry of Rare Earth Coordination Complexes'
Article	137	5
Book chapter	3	1
Monograph	3	1

Table 1 showed the literature selected from 5 (five) articles, 1 (one) book chapter and 1 (one) monograph. The literature that will be collected is based on clear information about the year of publication, title, type of literature source and publisher. This paper can also examine to some references about analysis data such as metaanalysis, bibliometric and Visualized Analysis, a bibliometric analysis, evaluation on research effectiveness in a subject area [11-14].

Qualitative content analysis was conducted on five papers, including Synthesis, Structure and Reactivity of Monoguanidinate Rare Earth Metal Aminobenzyl Enolate Complexes [15], Photochemical property of two Ru (II) compounds based on 5-(2-pyrazinyl) tetrazole for cancer phototherapy by changing auxiliary ligand [16]. Synthesis, structure and luminescence properties of binary and ternary complexes of lanthanide (Eu^{3+}, Sm^{3+}, and Tb^{3+}) with salicylic acid and 1,10-phenanthroline [17], Coordination complexes based on V-shaped ligandand rare earth (III) ion : Lanthanide contraction effect induced structural changes, coordination and silica surface chemistry of Lanthanides (III), Scandium (III)and Yttrium (III) sorption on 1-(2-pyridylazo)-2-napththol (PAN) and acetyla-cetone (acac) immobilized gels [18]. Book and monograph were analyzed using qualitative content analysis, repectively, selective recovery of rare-earth elements from diluted aqueous streams using N- and O-coordination ligand-grafted organic – inorganic hybrid composites [19] and molecular modeling of transition metal and rare earth coordination compounds [20].

Qualitative content analysis on different types of literature requires categorization in order to have a clear scope [21]. Qualitative content analysis must have a clear scope or area of study as well as be consistent with systematic analysis. This categorization includes synthesis(1), characterization (solubility(2), crystal structure(3), physicochemical properties(4)), sustainable applications(5) and the field that plays a role(6). Furthermore, by providing coding in the categories that have been determined from the qualitative content analysis in the literature is show in Table 2.

3.2. The study of the chemistry of rare earth metal coordination complexes can enhance systems thinking

Rare earth metal is one of the strategic minerals whose abundance in nature is still very limited. Based on the research results, minerals containing rare earth elements are present as by-products from mining products [22]. Rare earth metal has an opportunity as a strategic product because it is used as a material in the manufacturing of magnets, electronics, LED lighting, etc. [23]. The element Neodymium (Nd) has dielectric properties, ferroelectricity is used for applications in the field of microelectronics and microelectromechanical devices [24]. The advantages of rare earth metal include durable, recyclable, and recharging properties, thereby reducing the remaining material waste. Its environmentally friendly nature (green chemistry) has made more and more industries use rare earth metal as raw material and have begun to abandon chemicals that cause a lot of waste. The results showed the sustainable potential of the rare earth metal, so that it had an impact on the increasing research and development of the rare earth metal into the coordination complex compound. Research trends in the last 5 years have shown research on the synthesis of chemisrtry of rare earth metal coordination complexes from various elements of the lanthanide group. These chemistry of rare earth metal coordination complex compounds have characterization (solubility properties, crystal structure, physicochemical properties), continuous application and field relevance (Table 2).

Table 2. The results of qualitative content analysis

Coding	Category					Field representation (6)
	Synthesis (1)	Solubility (2)	Crystal structure (3)	Physicochemical properties (4)	Application by sustainability (5)	
a	Synthezed by $(CH_2C_6H_4NMe_2\text{-o})_2$ with THF (Tetrahydrofuran) through a metalization process, the most effective rare earth metals (RE = Y (1a, 73%), Lu (1b, 49%))	These coordination complexes are stable under the N_2 atmosphere and at room temperature, and are slightly soluble in hexane but readily soluble in polar and non-polar solvent THF	Examination of the molecular structure via X-ray crystallography shows the center of the yttrium is six-coordinated so that the geometric shape is distorted octahedral	It has luminesense properties, excellent luminescence.	Agriculture, medicine packaging and shipping. These compounds as a catalyst in ring-opening polymerizatin (ROP)	Society, economy
b	The compound that is reacted is cis-$[RuCl_2(bipy)_2]$ with NH4PF6. So that it will produce a complex compound $[Ru(pztz)(bipy)_2]$ [PF6]. Whereas in the synthesis of $[Ru(pztz)(phen)_2][PF_6]$, by reacting cis-$[RuCl_2(phen)_2]$ with NH_4PF_6	Dissoleves well in non-polar solvents.	Monocline crystal structure	Its generating light as photodynamic therapy	Magnets, Potodynamic Therapy (PDT), homogeneous catalysts, energized materials	Society, Environmental, economy,
c	The preparation of this complex is $(NH_4)[Ln(sal)_4(H_2O)_2]$ with 1,10-phenanthroline	Dissoleves well into polar solvents.	Monocline crystal structure	Its produces an emission spectrum well at a relatively wide wavelength. There are four emission peaks at the wavelengths of 594 nm, 618 nm, 654 nm, and 698 nm. Another property that is owned is flouroesens.	This compound has a distinctive emission from the Lanthanide ion so that it is used in various applications in many fields such as inorganic chemistry, biology and medicine.	Society, environmental
d	Synthesis in general $[Ln_2(SDB)_3(H2O)_5]_{n.}$ (Ln = Eu, Gd, Tb, Dy, Ho, Er, Tm, Y, Lu). For the synthesis of $[Eu_2(SDB)_3(H2O)_5]_n$, mix the crystalline solid $Eu(NO_3)_3.6H_2O$, with 4,4 sulfonyldibenzoic acid (H2SDB) anddeionized water. The process is continued with heating at 130^0C for three days. With the same process is also carried out to synthesize other chemistry of rare earth coordination complexes	Dissoleves well into polar solvents.	Monocline crystal structure	It has luminesense properties, excellent luminescence.	It is utilized as photochemical, chemical sensor, electro-luminescence.	environmental
e	The ligands used include 1-(2-pyridylazo)-	The solubility effect is	Monocline crystal	Its unique physicochemical	LED lamps, fluorescent	Economy,

Coding	Category					Field representation (6)
	Synthesis (1)	Solubility (2)	Crystal structure (3)	Physicochemical properties (4)	Application by sustainability (5)	
	2-napththol (PAN) and acetylaceton (acac) immobilized gels. The central metals used are Ln^{3+}, Sc^{3+}, dan Y^{3+} ions.	influenced by pH, temperature, interaction time, metal charge, functional group. In an acidic solution (pH = 2) it shows a dissolving efficiency of up to 50 - 60%.	structure	properties, optical and magnetic properties have contributed to the advancement of technologies such as lamps.	lamps, digital camera lenses, high performance permanent magnets, petroleum refining.	environmental, society
f	1-(2-Pyridylazo)-2-naphthol (PAN) PAN has the potential to produce colored complexes in reaction with REE. In experimental studies, the adsorbent prepared by the PAN Method II grafting procedure resulted in the formation of a colored solution.	Solubility well in organic solvents	Monocline crystal structure	It has luminesense properties, excellent luminescence.	As a photocatalyst	environmental
g	The synthesis of this coordination complex compound is derived from a rare earth metal, namely dysprosium and uses a ligand in the form of hexaamine.	Water solubility is very stable	Monocline crystal structure	These compounds are electron or electrochemical in nature	Its used in magnetic, optical spectroscopy and photophysics	Environmental, society

This study analyzed the qualitative content of 7 different types of literature, consisting of 5 articles, 1 book chapter and 1 monograph. The results of qualitative content analysis are shown in Table 2, showing that in codes a, b, c, d, e, f and g, in general, coordination complex compounds can be synthesized with various types of rare earth metals by reacting variations of ligands (inorganic or organic). The synthesis of rare earth metal coordination complexes is carried out by modifying various ligands with different mole ratios. The solubility test of coordination complex compounds resulting from the synthesis of rare earth metals is very stable in polar solvents such as water, THF and aromatic solvents, and several complex compounds are influenced by pH, temperature, reaction time, metal charge and functional groups. The crystalline structure of the chemistry of rare earth coordination complexes analyzed in the form of a monocline. Physicochemical properties are indicated by the appearance of emission spectra recorded at certain wavelengths. These physicochemical properties that the chemistry of rare earth coordination complexes can be applied to electronic technology such as LED lights, permanent magnets, optical spectroscopy, and equipment materials in the medical field. The synthetic products of the chemistry of rare earth coordination complexes can be utilized in the environmental, social and economic aspects. The coordination complex compounds analyzed have properties as future-based green chemistry materials. The trend of electronic industry products currently being developed is permanent magnets that can replace consumable magnets. These permanent magnets reduce the risk of chemical waste that can damage the environment. Chemical products obtained from the synthesis of the chemistry of coordination complexes compounds have green chemistry properties. The use of materials based green chemistry prioritizes the safety and security of people's lives in the world to be more secure. This is in line with the goals of the sustainable development of the United Nations program. Utilization of the coordination complexes compound as a safe chemical in the technology industry, to support increased economic income through sustainable technology industry activities.

The importance strengthen of the system thinking for bringing about the chemistry of rare earths coordination complexes to save future life on the earth [25]. The ability to think identification, analysis and prediction to connecting various synthesized chemistry of rare earth coordination complexes to the sustained nature [26]. The correlation between the chemistry of the chemistry of rare earth coordination complexes and its application in the relevant field can be shown in Figure 3.

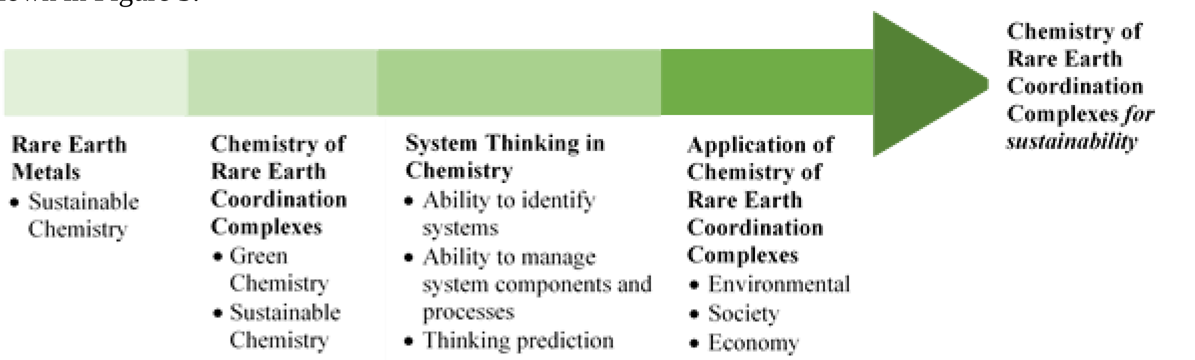

Figure 3. Framework of system thinking in chemistry of rare earth coordination complexes for sustaibility

Based on the results of a qualitative content analysis study of the chemistry of rare earth coordination complexes, the main categories were synthesis, characterization, application and other relevant fields. The correlation between these concepts can ignore systemic thought processes. In synthesizing the chemistry of rare earth coordination complexes, it begins with identifying the characteristics of the materials used such as the rare earth metals, then in the coordination complex compound formation process, the ability to identify the dynamic chemical bond interactions between the rare earth element as central metal and ligands is needed, then the ability to activated

the variables (concentration, pH, mol, temperature, etc.) which relate to the reaction process, solubility properties, crystal structure, and photochemical properties. System thinking skills can be improved through the ability to make generalizations when synthesizing chemistry of rare earth coordination complexes with defined characters. Furthermore, understanding about what components are not visible but have an effect on the synthesis result. The most important systems thinking process also lies in the ability to predict. The ability to predict must be possessed strongly to consider the character of the chemistry rare earth coordination complex, whether it contributes to safety for the environment, can be utilized for the community and has economic value. Optimizing systems thinking in chemical practice equals to saving sustainable future life. Therefore, the chemistry of rare earth coordination complexes is a material for sustainability. So that it can be generalized that the analyzed literature on the chemistry of rare earth coordination complexes has maximized the activities of systems thinking. Activities in this studies through experiments or research on innovation. Research in chemistry of rare earth coordination complexes that is carried out continuously will further strengthen the system thinking ability.

4. Conclusion

Chemistry of rare earth coordination complexes has characteristics as a sustainable compound based on the results of the qualitative content analysis of the literature. The analysis was carried out by linking the categories indicating the nature of sustainability. The categories are determined based on concepts that often appear in the literature which include synthesis, solubility, crystal structure, physicochemical properties, and their application in certain fields. In each category in this analysis, which begins with the synthesis of coordination complexes compounds to the continuous application, it requires a systematic thought process. System thinking process involves the ability to identify, analyze and predict so that there is a systemic correlation between components. Implementing the system thinking in the synthesis of rare earth metal coordination complexes can predict the order of products or materials to be produced.

The study of chemistry of rare earth coordination complexes can strengthen system thinking skills through activities in the form of the ability to identify, identify correlation between components, analyze, organize system components, and the ability to predict. In practice, its implementation can be applied in the industrial as well as in the world of chemistry education. In the industrial, it applies systems thinking, oriented to obtain green chemistry products of the Chemistry of rare earth coordination complexes that are safe environmentally, safe for the community, economical and used in a sustainable manner. In the education, students through the learning process can hone and strengthen the ability to system thinking by carrying out investigations into the Chemistry of rare earth coordination complexes. In general, the Chemistry of rare earth coordination complexes encourages the strengthening of system thinking abilities.

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