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The Misconception of Stoichiometry and Its Impact on the Chemical Equilibrium

Jusniar
Chemistry Department
Universitas Negeri Malang
Malang, Indonesia
jusniar@unm.ac.id

Effendi
Department of Chemistry
Universitas Negeri Malang
Malang, Indonesia
effendi.fmipa@um.ac.id

Endang Budiasih
Department of Chemistry
Universitas Negeri Malang
Malang, Indonesia
endang.budiasih.fmipa@um.ac.id

Sutrisno
Department of Chemistry
Universitas Negeri Malang
Malang, Indonesia
tris_chemum@yahoo.com

Abstract—Misconception about stoichiometry and its impact on the chemical equilibrium concept were studied on 245 second-grade students at SMA Negeri 2 Gowa, South Sulawesi, Indonesia. Research instruments were Stoichiometry misconception test (SMT) and chemical equilibrium misconception three tier tests (CEMTT). Semi structured interview was conducted after the administration of the test for fifteen students. SMT consisted of ten items with high validity of 90.70% and reliability coefficient, calculated using Cronbach's alpha, of 0.73 (high). CEMTT consisted of thirteen items with very high validity of 96.70% and reliability coefficient, calculated using Cronbach's alpha, of 0.95 (very high). The effect of stoichiometry misconceptions on chemical equilibrium was sufficient with limited predictions ($r = 0.36$). We identified three misconceptions stoichiometry that had impact on the misconceptions of chemical equilibrium concept namely: 1) The number of moles of substances that react is proportional to the number of atoms, relates to the increasing pressure will shift the equilibrium of the gas toward a substance that has more number of atoms; 2) The increasing of concentration will greater surface area, so as to giving rises to a greater number of effective collisions. This is related to the misconception that changes in the amount of solid phase at heterogeneous equilibrium which would shift the equilibrium system; 3) In exothermic reaction there is an increase in reaction enthalpy, relates to the misconception that the increase of temperature in exothermic gas equilibrium will shift towards the product. It was proven that there was a misconception relationship between the stoichiometry and chemical equilibrium, so it is recommended to implement a learning strategy that can prevent students' misconceptions on the concept of chemical equilibrium by eliminating students' misconceptions on the stoichiometry in chemistry learning.

Keywords—stoichiometry, chemical equilibrium, misconception

I. INTRODUCTION

Stoichiometry and chemical equilibrium are chemistry topics studied by high school science students. These topics consist of abstract concepts that important to study other chemistry topics such as acid-base equilibrium, solubility, and redox [1]. Abstract concepts can only be visualized at the atomic level, then to understand the chemical phenomenon requires the integration of three levels of

representation, namely macroscopic, submicroscopic and symbolic [2], [3].

According to Nakhleh [4] in order to obtain a complete understanding of chemical concepts required integration of conceptual and algorithmic understanding. Example simple equation for reaction nitrogen gases (N_2) with hydrogen gases (H_2) to ammonia gases. More students successfully balanced the equations. However, few of them could not explain the equation in the microscopic system. This makes the subject matter for the Stoichiometry, and Chemical Equilibrium becomes difficulty understood by students. These difficulties can lead to misconceptions if it happens continuously [5], [6]. Misconceptions are also called as alternative concepts [7] or *Spontaneous Knowledge* [8].

Misconception on stoichiometry course has been studied extensively. Huddle & Pillay [9] reported that the limiting reagent is the least number of moles. Garnet et al. [10] reported that the subscripts in formulae are numbers used in balancing equations and do not represent atomic groupings; equation coefficients are numbers used to mechanically balance equations and do not represent the relative numbers of species reacting or being produced in chemical reactions. Nakhleh [4] findings students misrepresentation of the chemical reaction equation due to lack of understanding of the difference between the reaction coefficients and subscripts of an element. Fang [11] reported two critical components for a conceptual understanding of the mole merged: (1) the number aspect of the mole needs to be justified by its mass aspect, and (2) the connection between molar mass and relative atomic/molecular mass.

Some misconceptions on chemical equilibrium concept had been reported: misconceptions on the Le-Chatelier principle about changes in gas volume, concentration, and temperature [1], [10], [12]–[14]. Heikkinen [15] reported that equilibrium conditions occur when both sides are equal and static. Misconceptions about dynamic equilibrium reported by [5], [16], [17]. The misconception about adding solids to a gas equilibrium system which would change the price of K and shift the equilibrium position reported by [5], [13] and [18]. Misconception that catalyst addition can increase product concentration reported by [10], [19], [20]. As well as misconceptions about the addition of inert gases, and determination of substance concentration in equilibrium

conditions had been reported by [12], [14], [16], [19], [21], [22].

Misconceptions can come from the teacher and the students' prior conception [16], textbooks [23], and preliminary knowledge or prerequisites [22]. [13] reported that the misunderstanding of the Le-Chatelier principle about changes in gas volume is caused by a lack of understanding of the concentration concept, difficulty interpreting mathematical language in stoichiometry reactions. According to [6] misunderstanding of the concept of equilibrium can be caused by incomplete explanations and misinterpretation of language. [10] reported that students' misconceptions on chemical concepts including chemical equilibrium were caused by inappropriate language use in everyday language in a scientific context. Experts suspect that the occurrence of misconceptions in chemical equilibrium is partly due to misconceptions in stoichiometry concept as a precondition concept. So far, there has never been a study linking the misconception of stoichiometry with chemical equilibrium.

The aims of the study were (1) to find out the impact of misconceptions on stoichiometry to misconceptions on chemical equilibrium 2) to find out misconceptions on stoichiometry which is related to the misconceptions of Chemical Equilibrium.

II. METHOD

The study is survey research to find out the main misconception on stoichiometry and chemical equilibrium, then further investigate the impact students' misconceptions on stoichiometry to the misconceptions of Chemical Equilibrium. The research carried out to 245 students grade XI SMA Negeri Gowa, Gowa, province of South Sulawesi, Indonesia. These students are from 8 groups that are homogeneous and have studied the material of stoichiometry and chemical equilibrium.

Research data are collected using a three-tier stoichiometry misconception test (SMT) and three-tier chemical equilibrium misconception test (CEMTT), followed with a semi-structured interview. SMT consisted of 10 items with high validity judged by three experts of 90.70% and reliability coefficient, calculated using Cronbach's alpha of high (0.730). CEMTT consisted of 30 items with very high validity of 96.70% and reliability coefficient, calculated using Cronbach's alpha of very high (0.95). Semi-structured interview was conducted after the administration of the test for fifteen students. Interviews carried out to trace the consistency students misconceptions of stoichiometric related to misconception on chemical equilibrium. Scoring for the correct answer in the first tier (answer) rated 1, and the wrong answer rated 0. The correct answer for the second tier (reason) if it was correct rated 1 and if it was wrong rated 0. For tier 3 was to measure the level of student confidence in answering with sure choice (III), not sure (II) and guessing (I). The total score for SMT was 20 while for CEMTT was 30. The tests were conducted in two stages: the first SMT test on March 26, 2018, and the second EMT test on March 30, 2018. Students experiencing misconceptions were determined from scoring by adapting [24], [25], ie if 1) correct answer, wrong reason and sure; 2) the wrong answer, right reason and sure; 3) wrong answer and reason and sure. The distribution of students' answers whose misconceptions are then classified based on the

pattern of answers and reasons, then tabulated the number of misconceptions and percentage — analyzing students' misconceptions on reaction rates and chemical equilibrium concept in accordance with the categories of [26], the percentage of misconceptions greater than 20.0%. Describing the misconceptions of reaction rates potentially impact to misconceptions on chemical equilibrium. This result is supported by a semi-structured interview from 15 students who consistently experience misconceptions at reaction rate and chemical equilibrium [1]. The interview recordings were transcribed and validated its conformity by two chemistry teachers at SMA Negeri 2 Gowa.

The effect of reaction rate misconception to chemical equilibrium misconception is determined by correlation analysis between the number of student misconceptions on reaction rate with the number of student misconception on chemical equilibrium. The analysis used Spearman's rho correlation with SPSS program because data of the number of students misconceptions on stoichiometry and chemical equilibrium are not normally distributed.

III. FINDINGS

The student misconceptions on stoichiometry can be seen in Table 1 and misconceptions on chemical equilibrium in Table 2.

TABLE I. MISCONCEPTIONS OF STOICHIOMETRY FOR STUDENTS GRADE XI SMA NEGERI 2 GOWA (N = 245)

Misconception of Stoichiometry	%
The number of moles of reactant and product is proportional to the number of index elements in substances	22.9
The number of moles of substances is inversely proportional to the reaction coefficient	30.2
Dissociation reactions are reactions in which a bond breaks between molecules.	20.8
The increasing of concentration will greater surface area, so as to give rises a greater number of effective collisions.	22.0
In exothermic reaction, there is an increase in reaction enthalpy.	24.9

TABLE II. MISCONCEPTIONS OF CHEMICAL EQUILIBRIUM FOR STUDENTS GRADE XI SMA NEGERI 2 GOWA (N = 245)

Misconception of Chemical Equilibrium	%
The rate of the increasing number of reactants in equilibrium conditions is faster than the reducing number of products	24.9
The rate of forwarding reaction will be higher than the rate of the reverse reaction under equilibrium conditions.	27.3
The rate of forwarding and reverse reaction remains in equilibrium because the concentration of substances has the same price.	20.3
The increasing volume of gas equilibrium system will shift the equilibrium to a larger number of subscripts an element.	32.2
The rate of the forward and the reverse reaction changes in dynamic equilibrium because of the number of reactants and products changes as well	20.8
Catalysts can increase the activation energy, so that the forward reaction rate is faster than the reverse reaction rate.	23.3
The changes in the number of solid phase substances in heterogeneous equilibrium will shift the equilibrium system.	22.9
The equilibrium constant is the result of the product concentration with the reactants (all phases) being raised by their respective coefficients.	68.3
The increasing temperature in exothermic gas equilibrium will shift towards the product.	27.3

The effect of stoichiometry to chemical equilibrium misconception using Spearman's rho correlation found a

significant relationship with a correlation coefficient ($r = 0.36$). The relationship category of the two variables is sufficient with limited predictions [27].

Based on the misconceptions that had been described in Table 1 and Table 2, there are some misconceptions on the stoichiometry related to the misconception of Chemical Equilibrium can be seen in Table 3.

TABLE III. MISCONCEPTION ON THE STOICHIOMETRY RELATED TO THE MISCONCEPTION OF CHEMICAL EQUILIBRIUM (N = 245)

Misconception of Stoichiometry – Related to Misconception of Chemical Equilibrium	(%)
The number of moles of substances that react is proportional to the number of index an element - related to	22.9
The increasing volume of gas equilibrium system will shift the equilibrium to a larger number of atoms	32.2
The increasing of concentration will greater surface area, so as to give rises a greater number of effective collisions. related to	22.0
The changes in the number of solid phase substances in heterogeneous equilibrium will shift the equilibrium system.	22.9
In exothermic reaction, there is an increase in reaction enthalpy. related to	24.9
The increasing temperature in exothermic gas equilibrium will shift towards the product.	27.3

IV. DISCUSSION

The misconception on "The number of moles of substances that react is proportional to the number of atoms" was related to the misconception on "the increasing volume of gas equilibrium system will shift the equilibrium to the larger number of atoms."

Students' misconceptions that the number of moles of substances that react is proportional to the number of atoms revealed at SMT points 1 and 7. This misconception was experienced by 22.9% of students and was related to the misconception on the increasing volume of gas equilibrium system that will shift the equilibrium to a large number of atoms. This misconception was revealed in CEMTT items 20 and 21 experienced by 32.2% of students. The interview footage between Researcher (R) with students (S1) that supported this misconception was:

R : What is your answer to item 1 SMT?

S1 : My answer is D-2. The amount of mol oxygen to combustion of propane is 5 moles.

R : What is your reason?

S1 : The number of moles is proportional to the coefficient and a number of atomic substances.

R : What is your answer to item 25 CEMTT?

S1 : My answer that will shift to the right side.

R : Why?

S1 : Because the increasing pressure of the equilibrium system will shift to a large number of molecules of gas.

The misconception that the number of moles of a substance is proportional to the number of atoms of a substance is due to students' lack of understanding of the difference between the reaction coefficients and the subscripts of an element. This had also been reported by [4] that students misinterpretation of the chemical reaction equation due to lack of understanding of the difference

between the reaction coefficients and subscripts of an element.

The misconception "the increasing of concentration of solution will increase the surface area of the reactants" associated with the misconception on "the change in the number of solid phase substances in heterogeneous equilibrium will shift the equilibrium system."

Students' misconceptions that the increase concentration of solution will increase the surface area of substances revealed at SMT point 6, this misconception was experienced by 22% of students. This misconception was related to the misconception that the changes in the number of solid phase substances in heterogeneous equilibrium will shift the equilibrium system. This misconception was revealed in CEMTT item 20 and was experienced by 22.9% of students. The interview footage with Researcher (R) with students (S2) who supported this misconception was as follows.

R : Please, take a look at the data in item 6. According to your opinion, what is the most appropriate answer?

S2 : The rate of the reaction is affected by the surface area of the reactant.

R : What is your reason?

S2 : The increasing of reactant concentration will facilitate collisions among molecules that affect the surface area of the reactants,

R : Why do you answer the rate of reaction influenced by the area surface? Meanwhile, your reason was the increasing concentration?

S2 : Like this. Concentration is related to surface area, the higher the concentration, the greater the surface area.

R : Do you think the surface area applies to the solution?

S4 : Yes ...

The misconception about the changing of the amount of solid phase substances on gas equilibrium will shift the equilibrium system that had been reported by [5] the first-year student of science education study program in Turkey, [18] at Izmir Turkey Middle School; [17] for high school students in Malaysia.

The misconception of "In exothermic reaction, there is an increase in reaction enthalpy, associated with increasing temperature in exothermic gas equilibrium will shift towards the product."

Misconceptions about characteristic exothermic reaction revealed at SMT points 9 and 10. This misconception was experienced by 24.9% of students. This was related to the misconception of equilibrium that the increasing temperature in exothermic gas equilibrium will shift towards the product. This misconception was revealed by CEMTT items 21 and 22 as many as 27.3% of students experienced this misconception. This finding was similar to that reported by [28] in high school and first-level students in Turkey. The interview footage between Researcher (R) and students (S3) supports the misconception.

R : what is the characteristic of the exothermic reaction?

S3 : enthalpy of product reaction higher than reactan.

R : why?

S3 : because $\Delta H > 0$.

- R : What is your answer to item 21 CEMTTT?
- S3 : the increasing temperature, equilibrium shift to the right.
- 2 R : Why?
- S3 : because the concentration of product will increase with increasing temperature.

V. CONCLUSIONS

The effect of stoichiometry to chemical equilibrium misconception using Spearman's rho correlation found a significant relationship with a correlation coefficient ($r = 0.36$). The relationship category of variables is sufficient with limited predictions. The misconceptions of the stoichiometry that was directly related to the misconception of chemical equilibrium were as follows: 1) The number of moles of reactant and product is proportional to the number of index an element substances, related with the increasing volume of gas equilibrium system will shift the equilibrium to a larger number of index atoms, 2) The increasing of concentration will greater surface area, so as to giving rises a greater number of subscript of element, 2) effective collisions, related to the changes in the number of solid phase substances in heterogeneous equilibrium will shift the equilibrium system, 3) In exothermic reaction there is an increase in reaction enthalpy related to The increasing temperature in exothermic gas equilibrium will shift towards the product. The implication in chemistry learning is important to implement a learning strategy that can prevent students' misconceptions on chemical equilibrium concept by eliminating students' misconceptions on the stoichiometry.

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