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On 0-Minimal (0, 2)-Bi-Hyperideal of Semihypergroups

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Abstract In this paper, the notions of $(0,2)$-hyperideals, $(1,2)$-hyperideals, bi-hyperideals and $(0,2)$-bi-hyperideals in semihypergroups are introduced and described. Basic properties of minimal $(0,2)$-bi-hyperideals of semihypergroups are considered. The results obtained extend the results on semigroup.

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1. Introduction

Hyperstructures are a generalization of a classical algebraic structure, and they were introduced by the French mathematician F. Marty [1]. In a classical algebraic structure, the composition of two elements is an element; while in algebraic hyperstructure, the composition of two elements is a set. In 2012, the notions of $(0,2)$-bi-hyperideal were introduced by S. Lekkoksung [2]. Moreover, S. Hobanthad and W. Jantanan [3] extended the results of bi-ideal in [4] to bi-hyperideal in semihypergroups. In this paper, the author would like to find conditions related to how a nonempty subset A of a semihypergroup H is only $(0,2)$-bi-hyperideal of H properly contained in A and prove that a semihypergroup H with zero is a 0-$(0,2)$-bisimple if and only if H is left 0-simple. The author also introduced the notions of $(0,2)$-bi-hyperideal and extended the results in [5] to semihypergroups.

2. Preliminaries

The rest of this section terminology used throughout the paper. A hyperoperation on a nonempty set H is a map $\circ : H \times H \to P^*(H)$ where $P^*(H)$ is the family of nonempty subset of H. If A and B are nonempty subsets of H and $x \in H$, then we define:

$$A \circ B = \bigcup_{a\in A, b\in B} a \circ b;\ x \circ A = \{x\} \circ A \text{ and } A \circ x = A \circ \{x\}.$$

A semihypergroup is a system $(H, \circ)$ where H is nonempty set, $\circ$ is a hyperoperation on H and $(x \circ y) \circ z = x \circ (y \circ z)$ for all $x, y, z \in H$. An element e of a semihypergroup H is called an identity of $(H, \circ)$ if $x \in (x \circ e) \cap (e \circ x)$ for all $x \in H$, and it is called a scalar

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identity of $(H, \circ)$ if $(x \circ e) \cap (e \circ x) = \{x\}$ for all $x \in H$. A semihypergroup H with an element 0 such that $0 \circ x = x \circ 0 = \{0\}$ for all x in H, then 0 is said to be a zero element of H, and H is called a semihypergroup with zero.

A nonempty subset A of a semihypergroup H is called a subsemihypergroup of H if $A \circ A \subseteq A$ and if $H \circ A \subseteq A (A \circ H \subseteq A)$; then, A is called a left hyperideal (right hyperideal) of H. Moreover, if A is a left and a right hyperideal of H; then, it is called a hyperideal of H.

Definition 2.1. Let $(H, \circ)$ be a semihypergroup and m, n be non-negative integers. A subsemihypergroup A is called a (m, n)-hyperideal of H if $A^m \circ H \circ A^n \subseteq A$.

In the above definition, if $m = n = 1$, then a subsemihypergroup A of semihypergroup H is called a bi-hyperideal of H. If $m = 0$ and $n = 2$; then, a subsemihypergroup A of semihypergroup H is called $(0, 2)$-hyperideal of H.

3. Main Results

If A is a nonempty subsemihypergroup of semihypergroup H, it clearly demostrates that $A \cup H \circ A$, $A \cup A \circ H$ and $A \cup A \circ H \circ A$ are left hyperideal, right hyperideal and bi-hyperideal, respectively of H. Moreover,

$$\begin{aligned} H \circ (A \cup H \circ A^2)^2 &= H \circ (A \cup H \circ A^2) \circ (A \cup H \circ A^2) \\ &= H \circ A^2 \cup H^2 \circ A^3 \cup H \circ A \circ H \circ A^2 \cup H^2 \circ A^2 \circ H \circ A^2 \\ &\subseteq H \circ A^2 \cup H \circ A^2 \cup H \circ A^2 \cup H \circ A^2 \\ &= H \circ A^2 \\ &\subseteq A \cup H \circ A^2, \end{aligned}$$

it remains $A \cup H \circ A^2$ is a $(0, 2)$-hyperideal of H.

Lemma 3.1. *If A is a subsemihypergroup of semihypergroup H; then, A is $(0, 2)$-hyperideal of H if and only if A is a left hyperideal of some left hyperideal of H.*

Proof. Since $(A \cup H \circ A) \circ A = A^2 \cup H \circ A^2 \subseteq A \cup A = A$, A is a left hyperideal of $A \cup H \circ A$. Conversely, if A is a left hyperideal of left hyperideal L of H; then, $H \circ A^2 \subseteq H \circ L \circ A \subseteq L \circ A \subseteq A$. Therefore, A is $(0, 2)$-hyperideal of H. ■

Theorem 3.2. *Let A be a subsemihypergroup of a semihypergroup H. The following statments are equivalent.*

i) A is a $(1, 2)$-hyperideal of H.
ii) A is a left hyperideal of some bi-hyperideal of H.
iii) A is a bi-hyperideal of some left hyperideal of H.
iv) A is a $(0, 2)$-hyperideal of some right hyperideal of H.
v) A is a right hyperideal of some $(0, 2)$-hyperideal of H.

Proof. (i $\Rightarrow$ ii) Since $(A \cup A \circ H \circ A) \circ A = A^2 \cup A \circ H \circ A^2 \subseteq A \cup A = A$, A is a left hyperideal of bi-hyperideal $A \cup A \circ H \circ A$ of H.

(ii $\Rightarrow$ iii) Let A be a left hyperideal of some bi-hyperideal B of H. Consider:

$$\begin{aligned} A\circ(A\cup H\circ A)\circ A &= A^3\cup A\circ H\circ A^2 \\ &\subseteq A\cup B\circ H\circ B\circ A \\ &\subseteq A\cup B\circ A \\ &\subseteq A\cup A \\ &= A. \end{aligned}$$

Hence, A is a bi-hyperideal of $A\cup H\circ A$. Since $A\cup H\circ A$ is a left hyperideal of H; then, A is a bi-hyperideal of left hyperideal $A\cup H\circ A$ of H.
(iii $\Rightarrow$ iv) Assume that A is a bi-hyperideal of some left hyperideal L of H. Consider:

$$\begin{aligned} (A\cup A\circ H)\circ A^2 &= A^3\cup A\circ H\circ A^2 \\ &\subseteq A\cup A\circ H\circ L\circ A \\ &\subseteq A\cup A\circ L\circ A \\ &\subseteq A\circ A \\ &= A. \end{aligned}$$

Since $A\cup A\circ H$ is a right hyperideal of H, then A is a $(0,2)$-hayperideal of right hyperideal $A\cup A\circ H$ of H.
(iv $\Rightarrow$ v) Suppose that A is a $(0,2)$-hyperideal of some right hyperideal R of H. Consider:

$$\begin{aligned} A\circ(A\cup H\circ A^2) &= A^2\cup A\circ H\circ A^2 \\ &\subseteq A\cup R\circ H\circ A^2 \\ &\subseteq A\cup R\circ A^2 \\ &\subseteq A\cup A \\ &= A. \end{aligned}$$

Since $A\cup H\circ A^2$ is a $(0,2)$-hyperideal of H, A is a right hyperideal of $(0,2)$-hyperideal $A\cup H\circ A^2$ of H.
(v $\Rightarrow$ i) Assume that A is a right hyperideal of $(0,2)$-hyperideal R of H. Then, $A\circ H\circ A^2\subseteq A\circ H\circ R^2\subseteq A\circ R\subseteq A$. Hence, A is a $(1,2)$-hyperideal of H. ∎

Lemma 3.3. *A subsemihypergroup A of a semihypergroup H is a $(1,2)$-hyperideal if and only if there exist a $(0,2)$-hyperideal L of H and a right hyperideal R of H such that $R\circ L^2\subseteq A\subseteq R\cap L$.*

Proof. Let A be a $(1,2)$-hyperideal of H, $L=A\cup H\circ A^2$ and $R=A\cup A\circ H$. Consider:

$$\begin{aligned} R\circ L^2 &= (A\cup A\circ H)\circ(A\cup H\circ A^2)^2 \\ &= (A\cup A\circ H)\circ(A\cup H\circ A^2)\circ(A\cup H\circ A^2) \\ &= (A^2\cup A\circ H\circ A^2\cup A\circ H\circ A\cup A\circ H^2\circ A^2)\circ(A\cup H\circ A^2) \\ &= (A^2\cup A\circ H\circ A)\circ(A\cup H\circ A^2) \\ &= A^3\cup A^2\circ H\circ A^2\cup A\circ H\circ A^2\cup A\circ H\circ A\circ H\circ A^2 \\ &\subseteq A\cup A\circ H\circ A^2 \\ &= A. \end{aligned}$$

Hence $R \circ L^2 \subseteq A \subseteq R \cap L$. Conversely, let R be a right hyperideal of H and let L be a $(0,2)$-hyperideal of H such that $R \circ L^2 \subseteq A \subseteq R \cap L$. Then,

$$A \circ H \circ A^2 \subseteq (R \cap L) \circ H \circ (R \cap L) \circ (R \cap L) \subseteq R \circ H \circ L^2 \subseteq R \circ L^2 \subseteq A.$$

Thus A is a $(1,2)$-hyperideal of H. ■

Let H be a semihypergroup with zero, and L is a left hyperideal of H. Since $H \circ L^2 \subseteq H \circ L \subseteq L$; then, L is a $(0,2)$-hyperideal of H. Therefore, every left hyperideal of H is a $(0,2)$-hyperideal of H.

A left hyperideal, right hyperideal, hyperideal, $(0,2)$-hyperideal and $(0,2)$-bi-hyperideal A of a semihypergroup H with zero will be said to be 0-minimal if $A \neq \{0\}$ and $\{0\}$ is the only left hyperideal, right hyperideal, hyperideal, $(0,2)$-hyperideal, $(0,2)$-bi-hyperideal, respectively of H properly contained in A.

Lemma 3.4. *Let L be a 0-minimal left hyperideal of semihypergroup H with zero and A be a subsemihypergroup with zero of L. Then, A is a $(0,2)$-hyperideal of H if and only if $A^2 = \{0\}$ or $A = L$.*

Proof. Let L be a 0-minimal left hyperideal of semihypergroup H with zero and A be a subsemihypergroup with zero of H contained in L. Assume that A is a $(0,2)$-hyperideal of H. It easy to see that $H \circ A^2$ is a left hyperideal of H. Since $H \circ A^2 \subseteq A \subseteq L$, we have $H \circ A^2 = \{0\}$ or $H \circ A^2 = L$. If $H \circ A^2 = L$; then, $A = L$. If $H \circ A^2 = \{0\}$; then, $H \circ A^2 \subseteq A^2$, A^2 is a left hyperideal of H contained in L. Hence $A^2 = \{0\}$ or $A^2 = L$. If $A^2 = L$; then, $A = L$. Therefore, $A^2 = \{0\}$ or $A = L$. Conversely, if $A^2 = \{0\}$; then, $H \circ A^2 = H \circ \{0\} = \{0\} \subseteq A$. If $A = L$, then $H \circ A^2 = H \circ L^2 \subseteq H \circ L \subseteq L = A$. ■

Lemma 3.5. *Let L be a 0-minimal $(0,2)$-hyperideal of a semihypergroup H with zero. Then $L^2 = \{0\}$ or L is a 0-minimal left hyperideal of H.*

Proof. Since $H \circ L^2 \subseteq L$, so $H \circ (L^2)^2 = H \circ L^2 \circ L^2 \subseteq L \circ L^2 \subseteq L^2$. Hence L^2 is a $(0,2)$-hyperideal of H, contained in L. Then, $L^2 = \{0\}$ or $L^2 = L$. If $L^2 = L$, implies $H \circ L = H \circ L^2 \subseteq L$. Thus, L is a left hyperideal of H. Let $B \subseteq L$ and B is a left hyperideal of H such that $B \neq \{0\}$; so, $H \circ B^2 \subseteq H \circ B \subseteq B$. Thus, B is a $(0,2)$-hyperideal of H. Since L is a 0-minimal $(0,2)$-hyperideal of H; then, $B = L$. Therefore, L is a 0-minimal left hyperideal of H. ■

The following corollary follows from Lemma 3.4 and Lemma 3.5.

Corollary 3.6. *Let H be a semihypergroup without zero. Then, L is a minimal $(0,2)$-hyperideal of H if and only if L is a minimal left hyperideal of H.*

Lemma 3.7. *Let H be a semihypergroup without zero and let A be a nonempty subset of H. Then, A is a minimal $(2,1)$-hyperideal of H if and only if A is a minimal bi-hyperideal of H.*

Proof. Since $(A^2 \circ H \circ A)^2 \circ H \circ (A^2 \circ H \circ A) \subseteq A^2 \circ H \circ A$; then, $A^2 \circ H \circ A$ is a $(2,1)$-hyperideal of H. Since A is a minimal $(2,1)$-hyperideal of H; so, $A^2 \circ H \circ A = A$. Consider $A \circ H \circ A = A^2 \circ H \circ A \circ H \circ A \subseteq A^2 \circ H \circ A = A$; then, A is a bi-hyperideal of H. Assume that B is a nonempty subset of A and B is a bi-hyperideal of H. Since $B^2 \circ H \circ B \subseteq B^2 \subseteq B$; then, B is a $(2,1)$-hyperideal of H. Since A is a minimal $(2,1)$-hyperideal of H; so,

$B = A$. Therefore, A is a minimal bi-hyperideal of H. Conversely, let A be a minimal bi-hyperideal of H. Clearly, $A^2 \circ H \circ A \subseteq A \circ H \circ A \subseteq A$; so, A is a $(2,1)$-hyperideal of H. Let $B \subseteq A$ and $B^2 \circ H \circ B \subseteq B$. Consider $(B^2 \circ H \circ B) \circ H \circ (B^2 \circ H \circ B) \subseteq B^2 \circ H \circ B$; then, $B^2 \circ H \circ B$ is a bi-hyperideal of H. The result is $B^2 \circ H \circ B = A$. Since $B^2 \circ H \circ B \subseteq B$; so, $A \subseteq B$. Thus, $A = B$. Therefore, A is a minimal $(2,1)$-hyperideal of H. ■

Definition 3.8. A subsemihypergroup A of a semihypergroup H with zero is called a $(0,2)$-bi-hyperideal of H if A is a bi-hyperideal of H and also a $(0,2)$-hyperideal of H. A $(0,2)$-bi-hyperideal A of H is called 0-minimal if $A \neq \{0\}$ and $\{0\}$ is the only $(0,2)$-bi-hyperideal of H properly contained in A.

A semihypergroup H with zero is called a 0-$(0,2)$-bisimple if $H^2 \neq \{0\}$ and $\{0\}$ is the only proper $(0,2)$-bi-hyperideal of H.

Lemma 3.9. *Let A be a nonempty subset of a semihypergroup H without zero. Then A is a $(0,2)$-bi-hyperideal of H if and only if A is a hyperideal of some left hyperideal of H.*

Proof. Let A be a $(0,2)$-bi-hyperideal of H, i.e., $A \circ H \circ A \subseteq A$ and $H \circ A^2 \subseteq A$. Since $A \cup H \circ A$ is a left hyperideal of H, we have

$$\begin{aligned} A \circ (A \cup H \circ A) &= A^2 \cup A \circ H \circ A \\ &\subseteq A \cup A = A \quad \text{and} \\ (A \cup H \circ A) \circ A &= A^2 \cup H \circ A^2 \\ &\subseteq A \cup A = A. \end{aligned}$$

Therefore, A is a hyperideal of left hyperideal $A \cup H \circ A$ of H. Conversely, let A be a hyperideal of some left hyperideal L of H. By Lemma 3.1, A is a $(0,2)$-hyperideal of H. Since $A \circ H \circ A \subseteq A \circ H \circ L \subseteq A \circ L \subseteq A$. Thus, A is a bi-hyperideal of H. Therefore, A is a $(0,2)$-bi-hyperideal of H. ■

Theorem 3.10. *Let A be a 0-minimal $(0,2)$-bi-hyperideal of a semihypergroup H. Then exactly one of the following cases occures:*

i) $A = \{0, a\}, a^2 = \{0\}, a \circ H \circ a = \{0\}$
ii) $A = \{0, a\}, a^2 = \{0\}, a \circ H \circ a = A$
iii) $\forall a \in A \setminus \{0\}, H \circ a^2 = A$

Proof. Let $a \in A \setminus \{0\}$. Since $(H \circ a^2) \circ H \circ (H \circ a^2) \subseteq H \circ a^2$; so, $H \circ a^2$ is a bi-hyperideal of H. Morover, $H \circ a^2$ is a $(0,2)$-hyperideal, because $H \circ (H \circ a^2)^2 = H \circ H \circ a^2 \circ H \circ a^2 \subseteq H \circ a^2$. Since, $H \circ a^2 \subseteq H \circ A^2 \subseteq A$, it follows that $H \circ a^2$ is a $(0,2)$-bi-hyperideal contained in A. Therefore, $H \circ a^2 = \{0\}$ or $H \circ a^2 = A$. Let $H \circ a^2 = \{0\}$. The result is either $a \circ a = \{0\}$ or $a \circ a = \{a\}$ or $a \circ a = \{0, a\}$ or there exists $x \in a^2$ such that $x \notin \{0, a\}$. If $a \circ a = \{a\}$, this is imposible, because $a \in a \circ a \circ a \subseteq H \circ a^2 = \{0\}$. If $a \circ a = \{0, a\}$; so, $(a \circ a) \circ a = \{0, a\} \circ a = 0 \circ a \cup a \circ a = \{0\} \cup \{0, a\} = \{0, a\}$. This causes a contradiction, because $a \in a \circ a \circ a \subseteq H \circ a^2 = \{0\}$. If there exists $x \in a^2$ such that $x \notin \{0, a\}$; so, $x \in A$. Then, $\{0, x\} \subseteq \{0, x, a\} \subseteq A$. Since, $H \circ x \subseteq H \circ a^2 = \{0\}$; so, $H \circ x = \{0\}$. Thus,

$H \circ x^2 = (H \circ x) \circ x = \{0\}$. Consider:

$$\begin{aligned} H \circ (\{0, x\})^2 &= H \circ \{0, x\} \circ \{0, x\} \\ &= H \circ 0^2 \cup H \circ 0 \circ x \cup H \circ x \circ 0 \cup H \circ x^2 \\ &= \{0\} \\ &\subseteq \{0, x\}, \end{aligned}$$

so $\{0, x\}$ is a $(0, 2)$-hyperideal of H. Since

$$\begin{aligned} \{0, x\} \circ H \circ \{0, x\} &= 0 \circ H \circ 0 \cup 0 \circ H \circ x \cup x \circ H \circ 0 \cup x \circ H \circ x \\ &= x \circ H \circ x \\ &= x \circ \{0\} = \{0\} \subseteq \{0, x\}, \end{aligned}$$

so $\{0, x\}$ is a bi-hyperideal. Therefore, $\{0, x\}$ is a $(0, 2)$-bi-hyperideal of H contained in A. This is contradiction, because $\{0, x\} \neq A$ and A is a 0-minimal $(0, 2)$-bi-hyperideal of H. Thus, $a^2 = \{0\}$ and $A = \{0, a\}$. Since, $(a \circ H \circ a) \circ H \circ (a \circ H \circ a) \subseteq a \circ H \circ a$; so, $a \circ H \circ a$ is a bi-hyperideal of H, $a \circ H \circ a \subseteq A \circ H \circ A \subseteq A$ and

$$\begin{aligned} H \circ (a \circ H \circ a)^2 &= H \circ a \circ H \circ a \circ a \circ H \circ a \\ &= H \circ a \circ H \circ a^2 \circ H \circ a \\ &= \{0\} \subseteq a \circ H \circ a. \end{aligned}$$

Then, $a \circ H \circ a$ is a $(0, 2)$-bi-hyperideal of H. Therefore, $a \circ H \circ a = \{0\}$ or $a \circ H \circ a = A$. ∎

The following corollary follows from Theorem 3.10.

Corollary 3.11. *Let A be a 0-minimal $(0, 2)$-bi-hyperideal of H such that $A^2 \neq \{0\}$. Then $A = H \circ a^2$ for every $a \in A \setminus \{0\}$.*

Corollary 3.12. *A semihypergroup H with zero is 0-$(0, 2)$-bisimple if and only if $H \circ a^2 = H$ for every $a \in H \setminus \{0\}$.*

Proof. Let H be a 0-$(0, 2)$-bisimple; then, $H^2 \neq \{0\}$ and H is a 0-minimal $(0, 2)$-bi-hyperideal. According to Corollary 3.11, $H \circ a^2 = H$ for every $a \in H \setminus \{0\}$. Conversely, let A be a $(0, 2)$-bi-hyperideal of H and $a \in A \setminus \{0\}$. Then, $H = H \circ a^2 \subseteq H \circ A^2 \subseteq A$. Thus, $H = A$. Therefore, H is 0-$(0, 2)$-bisimple. ∎

Theorem 3.13. *A semihypergroup H with zero is 0-$(0, 2)$-bisimple if and only if H is left 0-simple.*

Proof. Since H is 0-$(0, 2)$-bisimple, $H^2 \neq \{0\}$ and H is a 0-minimal $(0, 2)$-bi-hyperideal of H. Let $A \subseteq H$ such that $H \circ A \subseteq A$, we have $H \circ A^2 \subseteq A \circ A \subseteq A$ and $A \circ H \circ A \subseteq A \circ A \subseteq A$. Thus, $A = H$. Therefore, H is a left 0-simple. Conversely, if H is a left 0-simple and $H \circ (H \circ a) \subseteq H \circ a$ such that $a \in H \setminus \{0\}$; so, $H \circ a$ is a left hyperideal contained in H. Thus, $H \circ a = H$. Hence $H \circ a^2 = (H \circ a) \circ a = H \circ a = H$. Since Corollary 3.12, H is a 0-$(0, 2)$-bisimple. ∎

Theorem 3.14. *Let A be a 0-minimal $(0, 2)$-bi-hyperideal of H. Then either $A^2 = \{0\}$ or A is left 0-simple.*

Proof. Let $A^2 \neq \{0\}$, according to Corollary 3.11, $H \circ a^2 = A$ for every $a \in A \setminus \{0\}$. Let $a \in A \setminus \{0\}$. Since $(A \circ a^2) \circ H \circ (A \circ a^2) \subseteq A \circ H \circ A \circ a^2 \subseteq A \circ a^2$, then $A \circ a^2$ is a bi-hyperideal. Since

$$\begin{aligned} H \circ (A \circ a^2)^2 &= H \circ A \circ a^2 \circ A \circ a^2 \\ &\subseteq H \circ a^2 \circ A \circ a^2 \\ &= A \circ A \circ a^2 \\ &\subseteq A \circ a^2, \end{aligned}$$

hence $A \circ a^2$ is a $(0,2)$-hyperideal. Therefore, $A \circ a^2$ is a $(0,2)$-bi-hyperideal of H. Then, $A \circ a^2 = \{0\}$ or $A \circ a^2 = A$. If $a^2 = \{0\}$, it is imposible; because $H \circ a^2 = A$. Thus $a^2 \neq \{0\}$ for every $a \in A$. Therefore, there exists $x \in a^2 \setminus \{0\}$. Since $x \in a^2 \subseteq A$, we have $x^2 \neq \{0\}$. Consider $x^2 \subseteq a^2 \circ a^2 = a^4$; then, $a^4 = a^2 \circ a^2 \subseteq A \circ a^2$. Thus $A \circ a^2 \neq \{0\}$. Therefore, $A \circ a^2 = A$. According to Corollary 3.12 and Theorem 3.13 , A is left 0-simple. ∎

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