InPrime: Indonesian Journal of Pure and Applied Mathematics
Vol. 7, No. 1 (2025), pp. 44 – 51, doi: 10.15408/inprime.v7i1.42170
p-ISSN 2686-5335, e-ISSN: 2716-2478

Completely Closed Filter in *BN*-Algebra

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Abstract

A *BN*-algebra $(A; *, 0)$ is a non-empty set A equipped with a binary operation $*$ and a constant 0, which satisfies the following axioms: $(B1)$ $a * a = 0$, $(B2)$ $a * 0 = a$, and (BN) $(a * b) * c = (0 * c) * (b * a)$ for all $a, b, c \in A$. A subset I of A is called an ideal in A if it satisfies (i) $0 \in I$, (ii) if $b \in I$ and $a * b \in I$ imply $a \in I$, for all $a, b \in A$. This paper presents an original investigation on the completely closed filter in BN-algebra, a topic that has not been extensively explored in previous research. The concepts of filter, closed filter, and completely closed filter in BN-algebra are defined, which can always be associated with the concept of an ideal in BN-algebra. It begins by defining a filter in BN-algebra and then providing additional conditions to make it a closed and completely closed filter. The results show that every filter in BN-algebra has a condition (*D*), and every non-empty subset of BN_1-algebra is a closed filter. Furthermore, every normal ideal in *BN*-algebra, ideal in Coxeter algebra, and subalgebra in *BN*$_1$-algebra is a completely closed filter.
Keywords: *BN*-algebra; completely closed filter; filter; ideal.

Abstrak

BN-Aljabar $(A; *, 0)$ *adalah himpunan tak kosong* A *yang dilengkapi dengan operasi biner* $*$ *dan konstanta* 0, *yang memenuhi aksioma berikut:* $(B1)$ $a * a = 0$, $(B2)$ $a * 0 = a$, *dan* (BN) $(a * b) * c = (0 * c) * (b * a)$ *untuk setiap* $a, b, c \in A$. *Subhimpunan* I *dari* A *disebut ideal di* A *jika memenuhi: (i)* $0 \in I$, *(ii) untuk setiap* $b \in I$ *dan* $a * b \in I$ *mengakibatkan* $a \in I$, *untuk setiap* $a, b \in A$. *Dalam artikel ini, kami menyajikan sebuah studi baru tentang filter tertutup lengkap dalam BN-aljabar, sebuah topik yang belum banyak dieksplorasi dalam penelitian sebelumnya. Konsep filter, filter tertutup, dan filter tertutup lengkap dalam BN-Aljabar didefinisikan, yang mana selalu dapat dikaitkan dengan konsep ideal dalam BN-Aljabar. Dimulai dengan mendefinisikan filter dalam BN-aljabar, kemudian memberikan kondisi tambahan untuk menjadikannya filter tertutup dan filter tertutup lengkap. Hasil yang diperoleh adalah setiap filter dalam BN-Aljabar dengan kondisi (D) dan setiap subset tak kosong dari* BN_1*-aljabar merupakan filter tertutup. Lebih jauh, setiap ideal normal dalam BN-aljabar, ideal dalam Coxeter aljabar, dan subaljabar dalam* BN_1*-aljabar merupakan filter tertutup lengkap.*
Kata Kunci: *BN-aljabar; filter tertutup lengkap; filter; ideal.*

2020MSC: 03G25, 03G10

1. INTRODUCTION

BN-algebra is a non-empty set A equipped with binary operations $*$ and constants 0, which satisfies the following axioms: $(B1)$ $a * a = 0$, $(B2)$ $a * 0 = a$, and (BN) $(a * b) * c = (0 * c) * (b * a)$ for all $a, b, c \in A$ [1]. A *BN* -algebra $(A; *, 0)$ that satisfies $(a * b) * c = a * (c * b)$ for all $a, b, c \in A$ is said to be a *BN*-algebra with condition (*D*). Then, Coxeter algebra is an algebra $(P; *, 0)$ that satisfies the axioms $(B1)$, $(B2)$, and (C) $(a * b) * c = a * (b * c)$ for all $a, b, c \in P$ [2]. These three algebras are related to each other, which is every Coxeter algebra is a *BN*-algebra and every *BN*-algebra with

*) Corresponding author
Submitted October 31st, 2024, Revised March 17th, 2025,
Accepted for publication March 21st, 2025, Published Online March 31st, 2025

condition (*D*) is a Coxeter algebra. The special form of *BN*-algebra is BN_1-algebra [3], namely *BN*-algebra $(A; *, 0)$ which satisfies $a = (a * b) * b$ for all $a, b \in A$.

One of the interesting topics in the study of algebraic structures is the concept of ideals. The ideal concept has been discussed in *BN*-algebra [4] and *B*-algebra [5]. In *BN*-algebra $(A; *, 0)$, a subset I of A is said to be ideal of A if it satisfies: (i) $0 \in I$ and (ii) for all $b \in I$ and $a * b \in I$ implies $a \in I$ for all $a, b \in A$. The properties derived from the ideal concept in *BN*-algebra encompass the relationship between ideals, subalgebras, and normal within *BN*-algebra. As an extension of the ideal concept, additional types of ideals in *BN*-algebra have been explored, such as *c*-ideal and n - ideal [6], as well as the concepts of r - ideal and $m - k$ - ideal [7] based on the concept of *r*-ideal and $m - k$ - ideal in incline [8]. The ideal concept has also been discussed in various algebraic structures, such as [9], [10], and [11].

The study of filter in algebraic structures is equivalent to the concepts of ideal, subalgebra, and normal, because they are all subsets of the algebraic structure. The filter concept has been discussed in *BH*-algebra [12] and *U-BG-BH* [12]. A filter in *BH*-algebra $(H; *, 0)$ is a non-empty subset F of H that meets the following two criteria: (*i*) if $x, y \in F$, then $y * (y * x) \in F$ and $x * (x * y) \in F$, and (*ii*) if $x \in F$ and $x * y = 0$, then $y \in F$. The concept of filters has also been discussed in other algebraic structures, such as filters in *BE*-transitive algebras [13], *BZ*-algebras [14], and cyclic *B*-algebras [15]. Research on filters is ongoing, highlighted by the introduction of concepts such as the Smarandache filter [16], Smarandache closed and completely filter [17], and q - filter [18]. The concepts of ideals and filters have also been discussed in Sheffer stroke algebras, such as Sheffer stroke *BN*-algebras [19], R_0-algebra [20], Ortholattices [21], relation Sheffer stroke and Hilbert algebra [22], filters of strong Sheffer stroke non-associative MV-algebras [23], and filter of Sheffer stroke *BG*-algebras [24].

In this paper, we present an original investigation on the completely closed filter in BN-algebra, a topic that has not been extensively explored in previous research, it is evident that the ideal concept and its various developments have been discussed in *BN*-algebra. However, the concept of filters, which has also been developed in other algebraic structures, has not been explored in *BN*-algebra. In fact, the filter concept in *BN*-algebra holds significant potential for development into various other types of filters. Therefore, this research focuses on discussing the concepts of filter, closed filter, and complete closed filter in *BN*-algebra, investigating their properties, and examining their relationships with ideals, subalgebras, and normal structures in *BN*-algebra, Coxeter algebra, *BN*-algebra with condition (*D*), and BN_1-algebra.

2. DEFINITIONS

In this section, some definitions and properties required in the construction of filters and complete closed filters in *BN*-algebra are given.

Definition 2.1. [1] *BN*-algebra is a non-empty set A with a binary operation $*$ and a constant 0 that satisfy the following axioms:

$(B1)$ $a * a = 0$,
$(B2)$ $a * 0 = a$,
(BN) $(a * b) * c = (0 * c) * (b * a)$,
for all $a, b, c \in A$.

Theorem 2.2. [1] Suppose $(A; *, 0)$ is a *BN*-algebra, then

(i) $0 * (0 * a) = a$,

(ii) $b * a = (0 * a) * (0 * b)$,
(iii) $(0 * a) * b = (0 * b) * a$,
(iv) if $a * b = 0$, then $b * a = 0$,
(v) if $0 * a = 0 * b$, then $a = b$,
(vi) $(a * c) * (b * c) = (c * b) * (c * a)$,
for all $a, b, c \in A$.

Definition 2.3. [1] A *BN*-algebra $(A; *, 0)$ that satisfies (D) $(a * b) * c = a * (c * b)$ for all $a, b, c \in A$ is said to be a *BN*-algebra with condition (*D*).

Theorem 2.4. [1] Suppose $(A; *, 0)$ is a *BN*-algebra with condition (*D*), then
(i) $0 * a = a$,
(ii) $a * b = b * a$,
for all $a, b, c \in A$.

Definition 2.5. [2] Coxeter algebra is a non-empty set C with a constant 0 and a binary operation $*$ that satisfies the following axioms:
$(B1)$ $a * a = 0$,
$(B2)$ $a * 0 = a$,
(C) $(a * b) * c = a * (b * c)$,
for all $a, b, c \in C$.

Theorem 2.6. [2] Suppose $(C; *, 0)$ be a Coxeter algebra, then
(i) $0 * a = a$,
(ii) $a * b = b * a$,
(iii) $(b * a) * b = a$,
(iv) if $a * b = c * b$, then $a = c$,
(v) if $b * a = b * c$, then $a = c$,
(vi) if $a * b = 0$, then $a = b$,
(vii) $a * (a * b) = b$,
for all $a, b, c \in C$.

Proposition 2.7. [1] If $(C; *, 0)$ is a Coxeter algebra, then $(C; *, 0)$ is a *BN*-algebra.

Proposition 2.8. [1] $(A; *, 0)$ is a *BN*-algebra with condition (*D*) if and only if $(A; *, 0)$ is a Coxeter algebra.

Definition 2.9. [3] A *BN*-algebra $(E; *, 0)$ that satisfies $a = (a * b) * b$ for all $a, b \in E$ is said to be a BN_1-algebra.

Theorem 2.10. [3] Suppose $(E; *, 0)$ is a BN_1-algebra, then
(i) $0 * a = a$,
(ii) $a = (a * b) * (0 * b)$,
(iii) $a * b = b * a$,
(iv) $a = b * (b * a)$,
(v) if $a * b = 0$, then $a = b$,
(vi) if $a * b = b$, then $a = 0$,
(vii) if $a * b = a$, then $b = 0$,

(viii) if $a * b = a * c$, then $b = c$,
for all $a, b, c \in E$.

Definition 2.11. [4] A non-empty subset I of *BN*-algebra A is called an ideal in A if it meets
(i). $0 \in I$, and
(ii). If $b \in I$ and $a * b \in I$, implies $a \in I$, for any $a, b \in A$.

Suppose $(A;*,0)$ is a *BN*-algebra. A non-empty subset S is called a subalgebra of A if it satisfies $a * b \in S$ for all $a, b \in S$. A non-empty set N of A is called a normal of A if for any $x * y, a * b \in N$ satisfying $(x * a) * (y * b) \in N$. In *BN*-algebra $(A; *,0)$ the operation $\wedge$ is defined as $a \wedge b = b * (b * a)$ for all $a, b \in A$.

Below are some properties of ideals in *BN*-algebra.

Let $(A; *, 0)$ be a *BN*-algebra. The relation $\leq$ is defined as $x \leq y$ if and only if $x * y = 0$ for all $x, y \in A$.

Proposition 2.12. [4] Suppose I is an ideal in *BN*-algebra A. If $a \leq b$ and $b \in I$, then $a \in I$ for all $a, b \in A$.

Proposition 2.13.[4] If I is a normal ideal in *BN*-algebra A, then I is a subalgebra in A.

Proposition 2.14. [4] Every ideal in Coxeter algebra is normal.

Definition 2.15. *BH*-algebra is a non-empty set H with a binary operation $*$ and a constant 0 which satisfies the following axioms:
$(B1)$ $a * a = 0$,
$(B2)$ $a * 0 = a$,
(BH) $a * b = 0$ and $b * a = 0$, implies $a = b$,
for all $a, b \in H$.

Definition 2.16. A filter in *BH*-algebra $(H; *,0)$ is a non-empty subset F of H that satisfy the following two criteria:
(i). if $x, y \in F$, then $y * (y * x) \in F$ and $x * (x * y) \in F$,
(ii). if $x \in F$ and $x * y = 0$, then $y \in F$.

3. RESULTS

In this section, the research results include the definitions of filters, closed filters, and complete closed filters in *BN*-algebra, along with their properties in *BN*-algebra, Coxeter algebra, *BN*-algebra with conditions (*D*), and BN_1-algebra.

Definition 3.1. A filter in *BN*-algebra $(A; *,0)$ is a non-empty subset F of A that satisfy the following conditions:
($F1$) if $a, b \in F$, then $a \wedge b \in F$ and $b \wedge a \in F$,
($F2$) if $a \in F$ and $a * b = 0$, then $b \in F$.

Definition 3.2. Let $(A; *,0)$ is a *BN*-algebra and F is a filter of A. F is called a closed filter if $0 * a \in F$ for all $a \in F$.

Definition 3.3. Let $(A; *, 0)$ is a *BN*-algebra and F is a filter of A. F is called a completely closed filter if $a * b \in F$ for all $a, b \in F$.

Example 1 . Given $A = \{0, 1, 2, 3\}$ are a *BN*-algebra defined in Table 1.

Table 1. Cayley table for $(A; *, 0)$

$*$	0	1	2	3
0	0	1	2	3
1	1	0	1	1
2	2	1	0	1
3	3	1	1	0

The ideals of A are $\{0\}, \{0,2\}, \{0,3\}, \{0, 2, 3\}, \{0, 1, 2, 3\}$. The filters of A is $\{0\}, \{1\}, \{2\}, \{3\}, \{0,1\}, \{0,2\}, \{0,3\}, \{0, 1, 2\}, \{0, 1, 3\}, \{0, 1, 2, 3\}$. Since in A applies $0 * a = a$ for all $a \in A$, then every filter in A is a closed filter. Completely closed filter in A is $\{0\}, \{0,1\}, \{0,2\}, \{0,3\}, \{0, 1, 2\}, \{0, 1, 3\}, \{0, 1, 2, 3\}$.

Based on Example 1, it can be concluded that there are ideals that are not filters, and vice versa. Below are given the properties of filters in *BN*-algebra, Coxeter algebra, *BN*-algebra with conditions (D), and BN_1-algebra.

Theorem 3.4. Suppose $(A; *, 0)$ is a *BN*-algebra and F a filter of A. If $0 \notin F$, then F is not a completely closed filter.

Proof.
Let $(A; *, 0)$ is a *BN*-algebra, F is a filter of A, and $0 \notin F$. This will be proven by contradiction. Assume that F is a completely closed filter, then for all $a \in F$, by using Axiom $(B1)$, we obtain $a * a = 0 \in F$. This contradicts the fact that $0 \notin F$. Therefore, F cannot be a completely closed filter.

Theorem 3.5. Suppose $(A; *, 0)$ is a *BN*-algebra. If N is a normal ideal in A, then
(i) N is a filter in A,
(ii) N is a completely closed filter in A.

Proof.
Suppose $(A; *, 0)$ is a *BN*-algebra.
(i). Since N is a normal ideal in A, then according to Proposition 2.13 we obtain N is a subalgebra of A. So, for all $a, b \in N$, we have $a * b \in N$ and $b * a \in N$, so that $a \wedge b = b * (b * a) \in N$ and $b \wedge a = a * (a * b) \in N$, which means that the condition $(F1)$ is satisfied. Now, if $a \in N$ and $a * b = 0$, using Theorem 2.2 (iv) we obtain $b * a = 0$. Since N is an ideal in A, then $0 \in N$, and hence $b * a = 0 \in N$, which $b \in N$. Thus, the condition $(F2)$ holds. Therefore, it is proven that N is a filter in A.
(ii). From (i) we have that N is a filter. Since N is a normal ideal in A, then according to Proposition 2.13, N is a subalgebra of A, so that for all $a, b \in N$ we obtain $a * b \in N$. Thus, it is proven that N is a completely closed filter in A.

Corollary 3.6. Let $(C; *, 0)$ be a Coxeter algebra. If I is an ideal in C, then I is a completely closed filter in C.

Proof.
Let $(C;*,0)$ be a Coxeter algebra. Since I is an ideal in C, then according to Proposition 2.14, I is a normal ideal of A. Since C is a Coxeter algebra, then from Proposition 2.7 we have that C is also a *BN*-algebra, and by Theorem 3.5 (i) we obtain that I is a filter in C. By using Theorem 3.5 (ii), we obtain that I is a completely closed filter in C.

Theorem 3.7. Suppose $(A;*,0)$ is a *BN*-algebra with condition (D). If F is a filter in A, then F is a closed filter in A.

Proof. Let $(A;*,0)$ is a *BN*-algebra with conditions (D) and F is a filter in A. By using Theorem 2.4 (i) we obtain that for all $a \in A$, $0 * a = a \in A$. So, it is proven that F is a closed filter in A.

Theorem 3.8. Let $(E;*,0)$ be a BN_1-algebra. If S is a non-empty subset of E, then
(i). S is a filter in E,
(ii). S is a closed filter in E.

Proof.
Let $(E;*,0)$ be a BN_1-algebra and S is a non-empty subset of E.
(i). By using Theorem 2.10 (iv), for all $a, b \in S$, we obtain $a \wedge b = b * (b * a) = a \in S$ and $b \wedge a = a * (a * b) = b \in S$, which means that the condition $(F1)$ is satisfied. Now, if let $a \in S$ and $a * b = 0$, then according to Theorem 2.10 (v) we have $a = b$, and hence $b \in S$, which means that the condition $(F2)$ is satisfied. Thus, it is proven that S is a filter in E.
(ii). From (i) it is obtained that S is a filter in E. By using Theorem 2.10 (i) we obtain that for all $a \in S$, $0 * a = a \in S$. Therefore, it is proven that S is a closed filter in E.

Theorem 3.9. Let $(E;*,0)$ be a BN_1-algebra. If S is a subalgebra of E, then S is a completely closed filter in E.

Proof.
Let $(E;*,0)$ be a BN_1-algebra and S is a subalgebra of E. It is clear that S is a nonempty subset of E. From Theorem 3.8 (i) we have that S is a filter of E. Since S is a subalgebra of E, then for all $a, b \in S$ we have $a * b \in S$. So, it is proven that N is a completely closed filter in E.

4. DISCUSSION

This study develops the concepts of filter, closed filter, and completely closed filter in *BN*-algebra, demonstrating how these concepts can model the ideal structure within the algebra. In *BN*-algebra, a filter can be turned into a closed filter by satisfying the additional condition that $0 * a \in F$ for every element $a \in F$. If this filter is also a subalgebra, it becomes a completely closed filter. These findings highlight the close relationship between filters and ideals in *BN*-algebra, enriching our understanding of the interaction between foundational concepts in algebra. Research by Abbass and Hamza [12] on filters in *U-BG-BH* algebras also shows that filters can represent the properties of ideals and subalgebras, aligning with the findings in this study.

Previous research on filters has mostly focused on *BH* or *U-BG* algebras, such as Abbass and Hamza's work, which delves into the basic properties of filters but does not link them to ideals in *BN*-algebra. This study fills that gap by showing that filters in *BN*-algebra can function as ideals, providing a new contribution to the *BN*-algebra theory literature. Additionally, research by Gemawati et al. [6]

on complete ideals and *n*-ideals primarily emphasizes the differences between various ideal types, whereas this study introduces a more comprehensive theory of filters, including closed filters and completely closed filters.

The findings have significant implications for the application of filter theory in more complex algebras, such as Coxeter algebras and BN_1-algebras. The introduced filter concepts offer a new way to understand the internal structure of these algebras. Moreover, this research provides insights into applying filter theory in other types of algebras, such as non-commutative algebras or quantum algebras, which share similar structures but with different filter properties, contributing to the further development of algebraic theory. Luhaib and Abbass [17] also explore filters in Smarandache algebras, which is related to the findings of this study.

However, this study has limitations, particularly in its focus on *BN*-algebra and BN_1-algebras. Other similar but more complex algebras have not been explored in depth. Future research could explore these other algebra types, such as commutative or non-commutative algebras, to broaden the application of the filter concept. Additionally, while the study demonstrates that every ideal in *BN*-algebra meeting certain conditions can become a completely closed filter, further research may investigate additional conditions or modifications that could refine the filter theory in more complex algebra contexts.

Future studies should focus on filters in more complex algebras, such as commutative and non-commutative algebras, and explore the relationship between filters and other algebraic concepts in category theory or representation theory. This would provide new insights into how filters can be used to understand other aspects of algebra and open up broader applications, as discussed by Zhang et al. [19] on *Q*-filters in quantum algebras.

5. CONCLUSIONS

In this article, the concepts of filter, closed filter, and completely closed filter in *BN*-algebra are defined. We begin by defining a filter F in *BN*-algebra $(A;*,0)$, and then provide additional conditions, namely for each $a \in F, 0 * a \in F$, making it a closed filter. If the filter is also subalgebraic, it is called a completely closed filter. From these definitions, properties are derived that establish the relationships between filters and ideals, normal subalgebras, and subalgebras in *BN*-algebra, Coxeter algebra, *BN*-algebra with condition (*D*), and BN_1-algebra.

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