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Computing Banhatti Indices of Networks

V R Kulli
Department of Mathematics, Gulbarga University, Gulbarga 585106, India.
E-mail: vrkulli @gmail.com.

Abstract. Chemical graph theory is a branch of graph theory whose focus of interest is to finding topological indices of chemical graphs which correlate well with chemical properties of the chemical molecules. In this paper, we compute Banhatti indices of different chemically interesting networks like silicate, chain silicate, oxide and honeycomb networks.

1 Introduction

Let $G = (V, E)$ be a simple connected graph. The degree $d_G(v)$ of a vertex v is the number of vertices adjacent to v. The edge connecting the vertices u and v will be denoted by uv. Let $d_G(e)$ denote the degree of an edge e in G, which is defined by $d_G(e) = d_G(u) + d_G(v) - 2$ with $e = uv$. We refer to [1] for undefined term and notation.

A chemical graph or a molecular graph is a simple graph related to the structure of a chemical compound. Each vertex of this graph represents an atom of the molecule and its edges to the bonds between atoms. A topological index is a numerical parameter mathematically derived from the graph structure. These indices are useful for establishing correlations between the structure of a molecular compound and its physico-chemical properties.

The first and second K-Banhatti indices of a graph were introduced by Kulli in [2]. They are respectively defined as,

$$B_1(G) = \sum_{ue}[d_G(u) + d_G(e)], \quad B_2(G) = \sum_{ue}[d_G(u)d_G(e)]$$

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where ue means that the vertex u and edge e are incident in G. These indices were studied, for example, in [3, 4]. The Banhatti and Zagreb indices are closed related, see [4].

In [5], Kulli introudced the first and second K-hyper-Banhatti indices of a graph to take account of the contributions of pairs of incident elements. They are respectively defined as

$$HB_1(G) = \sum_{ue}[d_G(u) + d_G(e)]^2, \quad HB_2(G) = \sum_{ue}[d_G(u)d_G(e)]^2$$

The modified first and second K-Banhatti indices of a graph G[6] are respectively defined as,

$${}^mB_1(G) = \sum_{ue} \frac{1}{d_G(u) + d_G(e)}, \quad {}^mB_2(G) = \sum_{ue} \frac{1}{d_G(u) + d_G(e)}$$

The sum connectivity Banhatti index [7] of a graph G is defined as,

$$SB(G) = \sum_{ue} \frac{1}{\sqrt{d_G(u) + d_G(e)}}.$$

The product connectivity Banhatti index [8] of a graph G is defined as,

$$PB(G) = \sum_{ue} \frac{1}{\sqrt{d_G(u) + d_G(e)}}.$$

Recently , some topological indices were studied, for example, in [9, 10, 11]. Motivated by the definition of the first and second K-Banhatti indices,we introduce the general first and second K-Banhatti indices of a chemical graph G. The general first and second K-Banhatti indices of a graph G are defined as,

$$B_1^a(G) = \sum_{ue}[d_G(u) + d_G(e)]^a, \quad B_2^a(G) = \sum_{ue}[d_G(u)d_G(e)]^a$$

where a is a real number. In this paper, we compute K-Banhatti indices, K-hyper Banhatti indices, modified K-Banhatti indices and connectivity Banhatti indices of different chemically interesting networks like silicate networks, chain silicate networks, oxide networks and honeycomb networks. For more information about networks see [12].

2 Results for Silicate Networks

Silicates are very important elements of Earth's crust. Sand and several minerals are constituted by silicates. Silicates are obtained by fusing metal oxides or metal carbonates with sand. A silicate network is symbolized by SL_n, where n is the number of hexagons between the center and boundary of SL_n. A silicate network of dimension two is shown in Figure 1. We compute general K-Banhatti indices for silicate networks.

Theorem 2.1. The general first and second K-Banhatti indices of SL_n silicate networks are given by,

$$(i).\quad B_1^a(SL_n) = 12 \times 7^a n + (18n^2 + 6n)(10^a + 13^a) + 2(18n^2 - 12n)16^a \tag{1}$$

$$(ii).\quad B_2^a(SL_n) = 12^{a+1}n + (18n^2 + 6n)(21^a + 42^a) + 2(18n^2 - 12n)60^a \tag{2}$$

Proof: Let $G = SL_n$ be the graph of silicate network with $|V(SL_n)| = 15n^2 + 3n$ and $|E(SL_n)| = 36n^2$. In SL_n, there are three types of edges based on the degree of the vertices of each edge. Further, by algebraic method, the

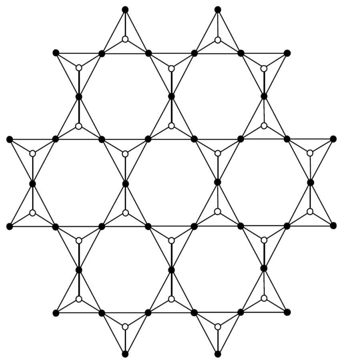

Figure 1: Silicate network of dimension two.

Table 1: Edge degree partition of $G = SL_n$

$d_G(u), d_G(v)\backslash e = uv \in E(G)$,	(3,3)	(3,6)	(6,6)
$d_G(e)$	4	7	10
Number of edges	6n	$18n^2 + 6n$	$18n^2 - 12n$

edge degree partition of a silicate network SL_n is given in Table 1.

(i). To compute $B_1^a(SL_n)$, we see that

$$\begin{aligned} B_1^a(SL_n) &= \sum_{ue}[d_G(u) + d_G(e)]^a \\ &= 6n[(3+4)^a + (3+4)^a] + (18n^2+6n)[(3+7)^a + (6+7)^a] \\ &\quad + (18n^2 - 12n)[(6+10)^a + (6+10)^a] \\ &= 12 \times 7^a n + (18n^2+6n)(10^a + 13^a) + (18n^2 - 12n)2 \times 16^a. \end{aligned} \tag{3}$$

(ii). To compute $B_2^a(SL_n)$, we see that

$$\begin{aligned} B_2^a(SL_n) &= \sum_{ue}[d_G(u)d_G(e)]^a \\ &= 6n[(3 \times 4)^a + (3 \times 4)^a] + (18n^2+6n)[(3 \times 7)^a + (6 \times 7)^a] \\ &\quad + (18n^2 - 12n)[(6 \times 10)^a + (6 \times 10)^a] \\ &= 12^{a+1}n + (18n^2+6n)(21^a + 42^a) + (18n^2 - 12n)2 \times 60^a. \end{aligned} \tag{4}$$

Corollary 2.1. The first K-Banhatti index of SL_n silicate network is given by $B_1(SL_n) = 9450n^2 - 870n$.

Proof: Put $a = 1$ in equation (1), we get the desired result.

Corollary 2.2. The first K-hyper Banhatti index of SL_n silicate network is given by $HB_1(SL_n) = 990n^2 - 162n$.

Proof: Put $a = 2$ in equation (1), we get the desired result.

Corollary 2.3. The sum connectivity Banhatti index of SL_n silicate network is given by, $SB(SL_n) = (\frac{1}{2} + \frac{1}{\sqrt{10}} + \frac{1}{\sqrt{13}})n^2 + (\frac{12}{\sqrt{7}} + \frac{6}{\sqrt{10}} + \frac{6}{\sqrt{13}} - 6)n$.

Proof: Put $a = -\frac{1}{2}$ in equation (1), we get the desired result.

Corollary 2.4. The modified first K-Banhatti index of SL_n silicate network is given by, ${}^mB_1(SL_n) = \frac{631}{260}n^2 + \frac{1161}{910}n$.

Proof : Put $a = -1$ in equation (1), we get the desired result.

Corollary 2.5. The second K-Banhatti index of SL_n silicate network is given by $B_2(SL_n) = 3294n^2 - 918n$.

Proof: Put $a = 1$ in equation (2), we get the desired result.

Corollary 2.6. The second K-hyper-Banhatti index of SL_n silicate network is given by $HB_2(SL_n) = 169290n^2 - 71442n$.

Proof: Put $a = 2$ in equation (2), we get the desired result.

Corollary 2.7. The product connectivity Banhatti index of SL_n silicate network is given by $PB(SL_n) = (\frac{18}{\sqrt{21}} + \frac{18}{\sqrt{15}})n^2 + (2\sqrt{3}\frac{6}{\sqrt{21}} + \frac{6}{\sqrt{42}} - \frac{12}{\sqrt{15}})n$.

Proof : Put $a = -\frac{1}{2}$ in equation (2), we get the desired result.

Corollary 2.8. The modified second K-Banhatti index of SL_n silicate network is given by ${}^mB_2(SL_n) = \frac{66}{35}n^2 + \frac{36}{35}n$.

Proof : Put $a = -1$ is equation (2), we get the desired result.

3 Results for Chain Silicate Networks

In this section, we consider a family of chain silicate networks. This network is symbolized by CS_n and is obtained by arranging n tetrahedra linearly, see Figure 2.

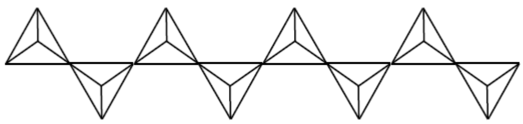

Figure 2: Chain silicate network.

We compute general K-Banhatti indices for chain silicate networks.

Theorem 3.1. The general first and second K-Banhatti indices of CS_n chain silicate networks are given by,

$$(i).\quad B_1^a(CS_n) = (2 \times 7^a + 4 \times 10^a + 4 \times 13^a + 2 \times 16^a)n + (8 \times 7^a - 2 \times 10^a - 2 \times 13^a - 4 \times 16^a) \qquad (5)$$

$$(i).\quad B_2^a(CS_n) = (2 \times 12^a + 4 \times 21^a + 4 \times 42^a + 2 \times 60^a)n + (8 \times 12^a - 2 \times 21^a - 2 \times 42^a - 4 \times 60^a) \qquad (6)$$

Proof: Let $G = CS_n$ be the graph of silicate network, $n \geq 2$. By algebraic method, we obtain $|V(CS_n)| = 3n + 1$ and $|E(CS_n)| = 6n$. Also in CS_n, there are three types of edges based on the degree of the vertices of each edge. Further, by algebraic method, the edge degree partition of a chain silicate network $CS_n, n \geq 2$ is given in Table 2.

(i). To compute $B_1^a(CS_n)$, we see that

Table 2: Edge degree partition of $CS_n, n \geq 2$.

$d_G(u), d_G(v) \backslash e = uv \in E(G),$	(3,3)	(3,6)	(6,6)
$d_G(e)$	4	7	10
Number of edges	$n+4$	$4n-2$	$n-2$

$$\begin{aligned} B_1^a(CS_n) &= \sum_{ue}[d_G(u)+d_G(e)]^a \\ &= (n+4)[(3+4)^a+(3+4)^a]+(4n-2)[(3+7)^a+(6+7)^a] \\ &\quad +(n-2)[(6+10)^a+(6+10)^a] \\ &= (2\times 7^a+4\times 10^a+4\times 13^a+2\times 16^a)n+(8\times 7^a-2\times 10^a-2\times 13^a-4\times 16^a). \end{aligned} \tag{7}$$

(ii). To compute $B_2^a(CS_n)$, we see that

$$\begin{aligned} B_2^a(CS_n) &= \sum_{ue}[d_G(u)d_G(e)]^a \\ &= (n+4)[(3\times 4)^a+(3\times 4)^a]+(4n-2)[(3\times 7)^a+(6\times 7)^a] \\ &\quad +(n-2)[(6\times 10)^a+(6\times 10)^a] \\ &= (2\times 12^a+4\times 21^a+4\times 42^a+2\times 60^a)n+(8\times 12^a-2\times 21^a-2\times 42^a-4\times 16^a). \end{aligned} \tag{8}$$

We obtain the following results by Theorem 3.1.

Corollary 3.1. The first K-Banhatti index of $CS_n, n \geq 2$ chain silicate network is given by $B_1(CS_n) = 138n - 54$.

Proof: Put $a = 1$ in equation (5), we get the desired result.

Corollary 3.2. The first K-hyper Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by $HB_1(CS_n) = 1686n - 1170$.

Proof: Put $a = 2$ in equation (5), we get the desired result.

Corollary 3.3. The sum connectivity Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by, $SB(CS_n) = (\frac{2}{\sqrt{7}} + \frac{4}{\sqrt{10}} + \frac{4}{\sqrt{13}} + \frac{1}{2})n + (\frac{8}{\sqrt{7}} - \frac{2}{\sqrt{10}} - \frac{2}{\sqrt{13}} - 1)$.

Proof: Put $a = -\frac{1}{2}$ in equation (5), we get the desired result.

Corollary 3.4. The modified first K-Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by, ${}^{m}B_1(CS_n) = \frac{4071}{3640}n + \frac{981}{1820}n$.

Proof : Put $a = -1$ in equation (5), we get the desired result.

Corollary 3.5. The second K-Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by $B_2(CS_n) = 396n - 270$.

Proof: Put $a = 1$ in equation (6), we get the desired result.

Corollary 3.6. The second K-hyper-Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by $HB_2(CS_n) = 16308n - 17658$.

Proof: Put $a = 2$ in equation (6), we get the desired result.

Corollary 3.7. The product connectivity Banhatti index of $CS_n, n \geq 2$, chain silicate network is given by $PB(CS_n) = (\frac{1}{\sqrt{3}} + \frac{4}{\sqrt{21}} + \frac{4}{\sqrt{42}} + \frac{1}{\sqrt{15}})n + (\frac{4}{\sqrt{3}} - \frac{2}{\sqrt{21}} - \frac{2}{\sqrt{42}} - \frac{2}{\sqrt{15}})$
Proof : Put $a = -\frac{1}{2}$ in equation (6), we get the desired result.

Corollary 3.8. The modified second K-Banhatti index of $CS_n, n \geq 2$, silicate network is given by ${}^mB_2(CS_n) = \frac{34}{70}n + \frac{16}{35}$.
Proof : Put $a = -1$ is equation (6), we get the desired result.

4 Results for Oxide Networks

The oxide networks are of vital importance in the study of silicate networks. An oxide network of dimension n is denoted by OX_n. A 5-dimensional oxide network is shown in Figure.3

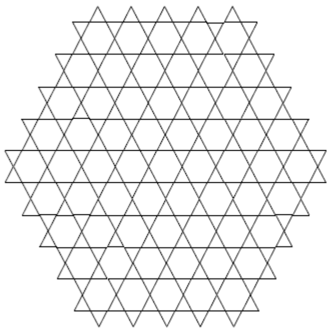

Figure 3: Oxide network of dimension 5

We compute the values of $B_1^a(OX_n)$ and $B_2^a(OX_n)$ for oxide networks.

Theorem 4.1. The general first and second K-Banhatti indices of OX_n oxide networks are given by,

$$(i).\quad B_1^a(OX_n) = 36 \times 10^a n^2 + (6^a + 8^a - 2 \times 10^a)12n \tag{9}$$

$$(ii).\quad B_2^a(OX_n) = 36 \times 24^a n^2 + (8^a + 16^a - 2 \times 24^a)12n \tag{10}$$

Proof: Let G be the graph of oxide network OX_n, see Figure 3. By algebraic method, G has $9n^2 + 3n$ vertices and $18n^2$ edges. In OX_n, there are two types of edges based on the degree of the vertices of each edge. Further by algebraic method, the edge degree partition of an oxide network OX_n is given in Table 3.

Table 3: Edge degree partition of OX_n.

$d_G(u), d_G(v) \backslash e = uv \in E(G)$,	(2,4)	(4,4)
$d_G(e)$	4	6
Number of edges	12n	$18n^2 - 12n$

(i). To compute $B_1^a(OX_n)$, we see that

$$\begin{aligned} B_1^a(OX_n) &= \sum_{ue}[d_G(u)+d_G(e)]^a \\ &= 12n[(2+4)^a+(4+4)^a]+(18n^2-12n)[(4+6)^a+(4+6)^a] \\ &= (36\times 10^a n^2+(6^a+8^a-2\times 10^a)12n. \end{aligned} \tag{11}$$

(ii). To compute $B_2^a(OX_n)$, we see that

$$\begin{aligned} B_2^a(OX_n) &= \sum_{ue}[d_G(u)d_G(e)]^a \\ &= 12n[(2\times 4)^a+(4\times 4)^a]+(18n^2-12n)[(4\times 6)^a+(4\times 6)^a] \\ &= 36\times 24^a n^2+(8^2+16^a-2\times 24^a)12n. \end{aligned} \tag{12}$$

We obtain the following results by Theorem 4.1.

Corollary 4.1. The first K-Banhatti index of OX_n oxide network is given by $B_1(OX_n)=360n^2-72n$.

Proof: Put $a=1$ in equation (9), we get the desired result.

Corollary 4.2. The first K-hyper Banhatti index of OX_n oxide network is given by $HB_1(OX_n)=3600n^2-1200n$.

Proof: Put $a=2$ in equation (9), we get the desired result.

Corollary 4.3. The sum connectivity Banhatti index of OX_n oxide network is given by, $SB(OX_n)=(\frac{36}{\sqrt{10}}n^2+(\frac{1}{\sqrt{6}}+\frac{1}{\sqrt{8}}+\frac{2}{\sqrt{10}})12n$.

Proof: Put $a=-\frac{1}{2}$ in equation (9), we get the desired result.

Corollary 4.4. The modified first K-Banhatti index of OX_n oxide network is given by, ${}^mB_1(OX_n)=\frac{18}{5}n^2+\frac{11}{10}n$.

Proof : Put $a=-1$ in equation (9), we get the desired result.

Corollary 4.5. The second K-Banhatti index of OX_n oxide network is given by $B_2(OX_n)=864n^2-288n$.

Proof: Put $a=1$ in equation (10), we get the desired result.

Corollary 4.6. The second K-hyper-Banhatti index of OX_n oxide network is given by $HB_2(OX_n)=20736n^2-932n$.

Proof: Put $a=2$ in equation (10), we get the desired result.

Corollary 4.7. The product connectivity Banhatti index of OX_n oxide network is given by $PB(OX_n)=(\frac{18}{\sqrt{6}}n^2+(\frac{1}{2\sqrt{2}}+\frac{1}{4}+\frac{1}{\sqrt{6}})n$ Proof : Put $a=-\frac{1}{2}$ in equation (10), we get the desired result.

Corollary 4.8. The modified second K-Banhatti index of OX_n oxide network is given by ${}^mB_2(OX_n)=\frac{3}{2}n^2+\frac{5}{48}n$.

Proof : Put $a=-1$ is equation (10), we get the desired result.

5 Results for Honeycomb Networks

If we recursively use hexagonal tiling in a particular pattern, honeycomb networks are formed. These networks are useful in chemistry and also in computer graphics. A honeycomb network of dimension n is denoted by HC_n, where n is the number of hexagons between central and boundary hexagon. A 4-dimensional honeycomb network is shown in Figure 4.

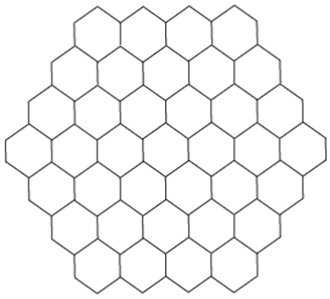

Figure 4: Honeycomb network of dimension 4.

We compute the values of $B_1^a(HC_n)$ and $B_2^a(OX_n)$ for honeycomb networks.

Theorem 5.1. The general first and second K-Banhatti indices of HC_n honeycomb networks are given by,

$$(i).\quad B_1^a(HC_n) = 12 \times 4^a + (12n-12)(5^a+6^a) + 2(9n^2-15n+6)7^a \tag{13}$$

$$(ii).\quad B_2^a(HC_n) = 12 \times 4^a + (12n-12)(6^a+9^a) + 2(9n^2-15n+6)12^a \tag{14}$$

Proof: Let G be the graph of honeycomb network HC_n with $6n^2$ vertices and $9n^2-3n$ edges. In HC_n, there are three types of edges based on the degree of the vertices of each edge. Further, by algebraic method, the edge degree partition of a honeycomb network HC_n is given in Table 4.

Table 4: Edge degree partition of HC_n.

$d_G(u), d_G(v) \backslash e = uv \in E(G)$,	(2,2)	(2,3)	(3,3)
$d_G(e)$	2	3	4
Number of edges	6	$12n-12$	$9n^2-15n+6$

(i). To compute $B_1^a(HC_n)$, we see that

$$\begin{aligned} B_1^a(HC_n) &= \sum_{ue}[d_G(u)+d_G(e)]^a \\ &= 6[(2+2)^a+(2+2)^a] + (12n-12)[(2+3)^a+(3+3)^a] \\ &\quad + (9n^2-15n+6)[(3+4)^a+(3+4)^a] \\ &= 12 \times 4^a + (12n-12)(5^a+6^a) + 2(9n^2-15n+6)7^a. \end{aligned} \tag{15}$$

(ii). To compute $B_2^a(HC_n)$, we see that

$$\begin{aligned} B_2^a(HC_n) &= \sum_{ue}[d_G(u)d_G(e)]^a \\ &= 6[(2\times 2)^a + (2\times 2)^a] + (12n-12)[(2\times 3)^a + (3\times 3)^a] \\ &\quad + (9n^2-15n+6)[(3\times 4)^a + (3\times 4)^a] \\ &= 12\times 4^a + (12n-12)(6^a+9^a) + 2(9n^2-15n+6)12^a. \end{aligned} \tag{16}$$

We obtain the following results by Theorem 5.1.

Corollary 5.1. The first K-Banhatti index of HC_n honeycomb network is given by $B_1(HC_n) = 126n^2 - 78n$.

Proof: Put $a = 1$ in equation (13), we get the desired result.

Corollary 5.2. The first K-hyper Banhatti index of HC_n honeycomb network is given by $HB_1(HC_n) = 882n^2 - 738n + 48$.

Proof: Put $a = 2$ in equation (13), we get the desired result.

Corollary 5.3. The sum connectivity Banhatti index of HC_n honeycomb network is given by, $SB(HC_n) = (\frac{18}{\sqrt{7}}n^2 + (\frac{12}{\sqrt{5}} + \frac{12}{\sqrt{6}} - \frac{30}{\sqrt{7}})n + (6 - \frac{12}{\sqrt{5}} - \frac{12}{\sqrt{6}} + \frac{12}{\sqrt{7}})$

Proof: Put $a = -\frac{1}{2}$ in equation (13), we get the desired result.

Corollary 5.4. The modified first K-Banhatti index of HC_n honeycomb network is given by, ${}^mB_1(HC_n) = \frac{18}{\sqrt{7}}n^2 + \frac{4}{35}n + \frac{11}{35}$.

Proof : Put $a = -1$ in equation (13), we get the desired result.

Corollary 5.5. The second K-Banhatti index of HC_n honeycomb network is given by $B_2(HC_n) = 216n^2 - 180n + 12$.

Proof: Put $a = 1$ in equation (14), we get the desired result.

Corollary 5.6. The second K-hyper-Banhatti index of HC_n honeycomb network is given by $HB_2(HC_n) = 2592n^2 - 2916n + 516$.

Proof: Put $a = 2$ in equation (14), we get the desired result.

Corollary 5.7. The product connectivity Banhatti index of HC_n honeycomb network is given by $PB(HC_n) = 3\sqrt{3}n^2 + (2\sqrt{6} + 4 - 5\sqrt{3})n + (2 - 2\sqrt{6} + 2\sqrt{3})$ Proof : Put $a = -\frac{1}{2}$ in equation (14), we get the desired result.

Corollary 5.8. The modified second K-Banhatti index of HC_n honeycomb network is given by ${}^mB_2(HC_n) = \frac{3}{2}n^2 + \frac{5}{6}n + \frac{2}{3}$.

Proof : Put $a = -1$ is equation (14), we get the desired result.

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