
IMAGE: A MAP OF THE STARS OF THE ORION CONSTELLATION

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# Journal Content
## In this Issue

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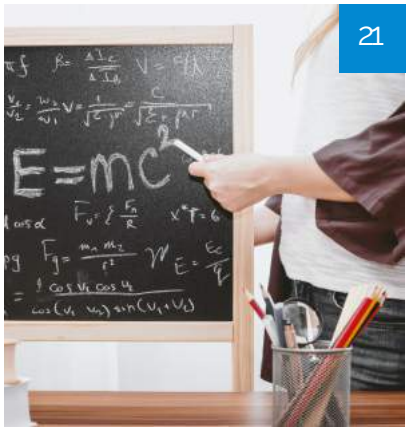



# Two Ways to Prove Goldbach Conjecture

*Xin Wang*

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## ABSTRACT

The Goldbach Conjecture is a recalcitrant problem in mathematics. Here the author tried to prove the Conjecture in two ways, hoping this result will accelerate related research.

*Keywords:* prime number, Goldbach Conjecture.

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*The Goldbach Conjecture is a recalcitrant problem in mathematics. Here the author tried to prove the Conjecture in two ways, hoping this result will accelerate related research.*

*Keywords:* prime number, goldbach conjecture.

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## I. INTRODUCTION

The Goldbach Conjecture states that every even number greater than 2 is a sum of two primes. This conjecture has been confirmed to be true for all evens up to 6 x $10^{16}$ [1]. However, theoretically, this Conjecture remains unproven to this date despite tedious efforts [1; 2; 3; 4]. Here I tried to give two proofs for the Conjecture.

*Proof 1:*

Theorem 1. If all primes smaller than or equal to $\sqrt{a}$ cannot divide a natural number $a$ exactly, then $a$ is a prime.

*Proof:* Suppose $a$ is a composite.

Since $a$ is a composite, $a$ can be expressed as a product of two natural numbers, namely, $a = b \times c$ ($b$ and $c$ are natural numbers).

If $b = c$, then $b = c = \sqrt{a}$. This contradicts the premise of the theorem.

If $b \neq c$, one of $b$ and $c$ must be smaller than $\sqrt{a}$. This contradicts the premise of the theorem, too.

Thus the above supposition ($a$ is a composite) cannot be true, therefore $a$ must be a prime.

This completes the proof of Theorem 1.

*Denotation:*

$a$ is a natural number greater than 3.
$p$ is an odd prime smaller than $a$.
P is a set of all $p$.
$n$ is the number of elements in P.
$p_i$ is the $i_{th}$ prime.
$p_t$ is the greatest prime that is smaller than $\sqrt{2a}$.

Theorem 2. Any natural number greater than 3 is the average of at least one pair of primes.

According to Theorem 1, if all prime factors smaller than or equal to $\sqrt{2a}$ cannot divide $2a$ exactly, $2a$ is a prime. Therefore whether $2a - p$ ($<2a$) being a prime can be sufficiently determined by dividing it







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using all odd primes smaller than $\sqrt{2a}$ as all values of $2a - p$ are odd. Theoretically, the minimal probability of numbers in the range $(a, 2a)$ is calculated as

$$\begin{aligned}
\text{prob}(2a) &= \frac{2}{3}\times\frac{4}{5}\times\frac{6}{7}\times\frac{10}{11}\times\frac{12}{13}\times\frac{16}{17}\times\cdots\cdots\times\frac{p_t-1}{p_t} \\
&= \frac{2}{3}\times\frac{3}{4}\times\frac{4}{5}\times\frac{5}{6}\times\frac{6}{7}\times\frac{7}{8}\times\frac{8}{9}\times\frac{9}{10}\times\frac{10}{11}\times\frac{11}{12}\times\frac{12}{13}\times\frac{13}{14}\times\frac{14}{15}\times\frac{15}{16}\times\frac{16}{17}\times\cdots\cdots\times\frac{\boldsymbol{p_t-2}}{\boldsymbol{p_t-1}}\times\frac{p_t-1}{p_t} \\
&\quad \times\frac{4}{3}\times\frac{6}{5}\times\frac{8}{7}\times\frac{9}{8}\times\frac{10}{9}\times\frac{12}{11}\times\frac{14}{13}\times\frac{15}{14}\times\frac{16}{15}\times\cdots\cdots\times\frac{\boldsymbol{p_t-1}}{\boldsymbol{p_t-2}} \\
&= \frac{2}{p_t}\times\frac{4}{3}\times\frac{6}{5}\times\frac{8}{7}\times\frac{9}{8}\times\frac{10}{9}\times\frac{12}{11}\times\frac{14}{13}\times\frac{15}{14}\times\frac{16}{15}\times\cdots\cdots\times\frac{\boldsymbol{p_t-1}}{\boldsymbol{p_t-2}} \\
&= \frac{2}{p_t}\times\frac{4}{3}\times\frac{6}{5}\times\frac{10}{7}\times\frac{12}{11}\times\frac{16}{13}\times\cdots\cdots\times\frac{\boldsymbol{p_t-1}}{\boldsymbol{p_{t-1}}} \\
&= \frac{2}{p_t}\times\frac{5-1}{3}\times\frac{7-1}{5}\times\frac{11-1}{7}\times\frac{13-1}{11}\times\frac{17-1}{13}\times\cdots\cdots\times\frac{p_t-1}{p_{t-1}} \\
&= \frac{2}{p_t}\times\prod_{i=2}^{t-1}\frac{p_{i+1}-1}{p_i}
\end{aligned} \qquad 1)$$

As the number of different values of $2a - p$ in (a, 2a) is equal to the number of elements in P (namely, $n$), the minimal number of primes in form of $2a - p$ can be under-calculated as following, as prob($2a$-$p$) > prob($2a$) since probability of primes is increasingly reduced as the range extends and $2a > 2a - p$.

$$n\times\text{prob}(2a-p) > n\times\text{prob}(2a) = \frac{2n}{p_t}\times\prod_{i=2}^{t-1}\frac{p_{i+1}-1}{p_i} \qquad 2)$$

In Formula 2, $n = \pi(a) = O(a/\ln a)$, $P_t = O(\sqrt{2a})$, so $\frac{2n}{P_t}$ increases with $a$, and $\prod_{i=2}^{t-1}\frac{p_{i+1}-1}{p_i}$ monotonously increases regardless of the value of $a$. So it is easy to conclude that the above estimation in Formula 2 generally increases with $a$.

Despite such underestimations, it is clear that the estimated numbers of primes in form of $(2a - p)$ in $(a, 2a)$ are always greater than 1 when $a > 5$ and continue to increase, meaning that, there are at least one pair of primes, $p$ and $2a - p$, with their average equal to $a$, as shown in Figure 1. This completes proof 1 of Theorem 2.

*Table 1:* Although it may be as small as a fraction of 1 in the second example, the estimated numbers of primes in form of $2a - p$ in (a, 2a) are always greater than 1 in other examples, indicating that there are at least one pair of primes, $p$ and $2a - p$, with their average equal to every natural number $a$.

| $a$ | $2a$ | $\sqrt{2a}$ | $n$ | $p_t$ | Minimal calculated probability of being primes of numbers in form $(2a - p)$ | estimated number of primes in form of $(2a - p)$ | actual number of primes in $(a, 2a)$ | annotations |
|---|---|---|---|---|---|---|---|---|
| 4 | 8 | 2.8 | 1 | 2 | 1 | 1 | 2 | Underestimated |
| 5 | 10 | 3.2 | 1 | 3 | 0.89 | 0.89 | 1 | Underestimated |
| 6 | 12 | 3.5 | 2 | 3 | 0.89 | 1.78 | 2 | Underestimated |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7 | 14 | 3.7 | 2 | 3 | 0.89 | 1.78 | 2 | Underestimated |
| 8 | 16 | 4 | 3 | 3 | 0.89 | 2.67 | 2 | ***Overestimated*** |
| 9 | 18 | 4.2 | 3 | 3 | 0.89 | 2.67 | 3 | Underestimated |
| 10 | 20 | 4.5 | 3 | 3 | 0.89 | 2.67 | 4 | Underestimated |
| 11 | 22 | 4.7 | 3 | 3 | 0.89 | 2.67 | 3 | Underestimated |
| 12 | 24 | 4.9 | 4 | 3 | 0.89 | 3.56 | 4 | Underestimated |
| 13 | 26 | 5.1 | 4 | 5 | 0.64 | 2.56 | 3 | Underestimated |
| 14 | 28 | 5.3 | 5 | 5 | 0.64 | 3.2 | 3 | ***Overestimated*** |
| 15 | 30 | 5.5 | 5 | 5 | 0.64 | 3.2 | 4 | Underestimated |
| 16 | 32 | 5.7 | 5 | 5 | 0.64 | 3.2 | 5 | Underestimated |
| 17 | 34 | 5.8 | 5 | 5 | 0.64 | 3.2 | 4 | Underestimated |
| 18 | 36 | 6 | 6 | 5 | 0.64 | 3.84 | 4 | Underestimated |
| 19 | 38 | 6.2 | 6 | 5 | 0.64 | 3.84 | 4 | Underestimated |
| 20 | 40 | 6.3 | 7 | 5 | 0.64 | 4.48 | 4 | ***Overestimated*** |
| 21 | 42 | 6.5 | 7 | 5 | 0.64 | 4.48 | 5 | Underestimated |
| 22 | 44 | 6.6 | 7 | 5 | 0.64 | 4.48 | 6 | Underestimated |
| 23 | 46 | 6.8 | 7 | 5 | 0.64 | 4.48 | 5 | Underestimated |
| 24 | 48 | 6.9 | 8 | 5 | 0.64 | 5.12 | 6 | Underestimated |
| 25 | 50 | 7.1 | 8 | 7 | 0.52 | 4.16 | 6 | Underestimated |
| 50 | 100 | 10 | 14 | 7 | 0.52 | 7.28 | 10 | Underestimated |
| 100 | 200 | 14.1 | 24 | 13 | 0.472 | 11.3 | 21 | Underestimated |
| 200 | 400 | 20 | 45 | 19 | 0.396 | 17.8 | 32 | Underestimated |
| 300 | 600 | 24.5 | 61 | 23 | 0.398 | 36.2 | 47 | Underestimated |
| 400 | 800 | 28.3 | 77 | 23 | 0.398 | 30.7 | 61 | Underestimated |
| 500 | 1000 | 31.6 | 94 | 31 | 0.355 | 33.4 | 73 | Underestimated |
| 600 | 1200 | 34.6 | 108 | 31 | 0.355 | 38.3 | 87 | Underestimated |
| 700 | 1400 | 37.4 | 124 | 37 | 0.322 | 39.9 | 97 | Underestimated |
| 800 | 1600 | 40 | 138 | 37 | 0.322 | 44.4 | 112 | Underestimated |
| 900 | 1800 | 42.4 | 153 | 41 | 0.297 | 45.4 | 124 | Underestimated |
| 1000 | 2000 | 44.7 | 167 | 43 | 0.303 | 50.6 | 135 | Underestimated |
| 2000 | 4000 | 63.2 | 302 | 61 | 0.267 | 80.6 | 247 | Underestimated |
| 3000 | 6000 | 77.5 | 429 | 73 | 0.257 | 110.3 | 353 | Underestimated |
| 4000 | 8000 | 89.4 | 549 | 89 | 0.25 | 137.3 | 457 | Underestimated |
| 5000 | 10000 | 100 | 668 | 97 | 0.236 | 157.7 | 560 | Underestimated |
| 6000 | 12000 | 109.5 | 782 | 109 | 0.227 | 177.5 | 655 | Underestimated |
| 7000 | 14000 | 118.3 | 899 | 113 | 0.244 | 219.4 | 752 | Underestimated |
| 8000 | 16000 | 126.5 | 1006 | 113 | 0.244 | 245.5 | 855 | Underestimated |
| 9000 | 18000 | 134.2 | 1116 | 131 | 0.227 | 253.3 | 947 | Underestimated |
| 10000 | 20000 | 141.4 | 1228 | 139 | 0.229 | 281.2 | 1033 | Underestimated |
| 100000 | 200000 | 447.2 | 9591 | 443 | 0.152 | 1457.8 | 8392 | Underestimated |
| 1000000 | 2000000 | 1414.2 | 78497 | 1409 | 0.1283 | 10071.1 | 70435 | Underestimated |
| 10000000 | 20000000 | 4472.1 | 664578 | 4463 | 0.1100655 | 73147.1 | 606028 | Underestimated |
| 100000000 | 200000000 | 14142.1 | 5761454 | 14107 | 0.09677885 | 557586.9 | 5317481 | Underestimated |

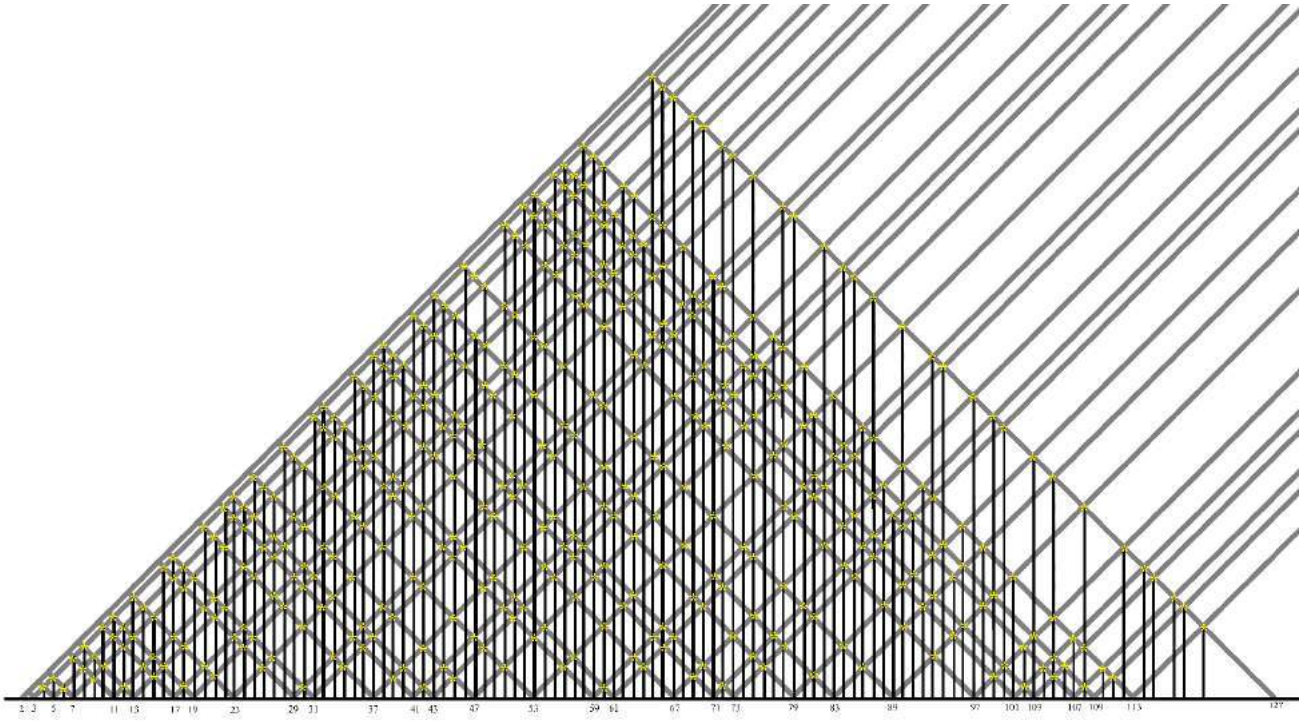

*Figure 1:* Every asterisk is the apex of an isosceles triangle, the left and right base angles are two primes, while base's midpoint is a natural number that is the averages of the two primes. The above rules applies for every natural number ≥4.

*Proof 2:*

Case 1. When $X_n = 30$

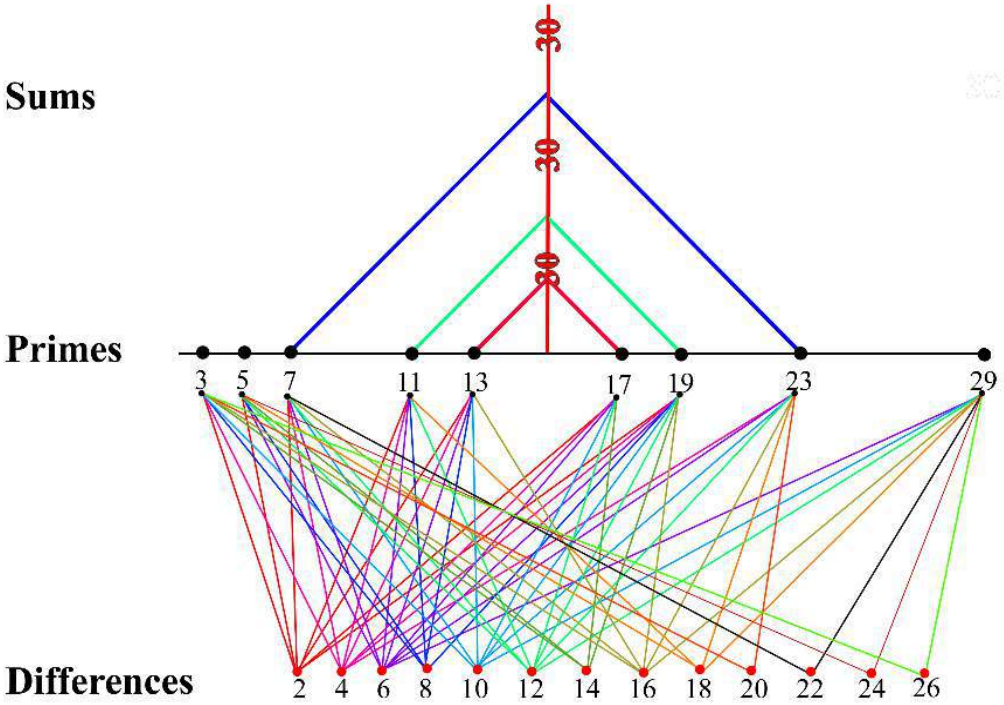


*Figure 2:* In the middle, odd primes smaller than 30 are plotted on an axis. Above the axis, six primes are paired and have sums equal to 30. Below the axis, even differences ranging from 2 to 26 are connected to their related primes.

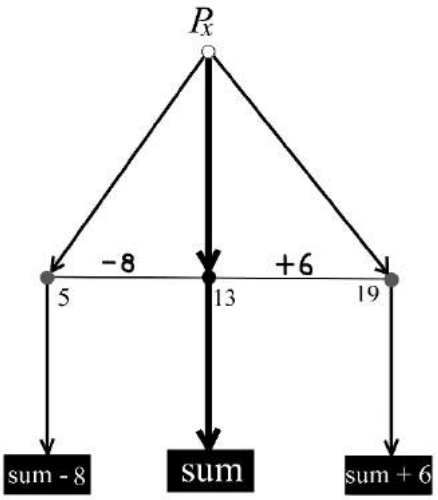


*Figure 3:* The sum of two primes, $P_x$ and 13, may be decreased or increased by the difference between two primes through replacing the latter number (13) with another prime smaller or greater than it. If putting $P_x$ and 13 together is termed as pairing, then replacing 13 in the pair with a different prime can be termed as re-pairing. Such re-pairing generates a sum different than the original one.

As proven previously [5], a super product of a prime tends to collect more prime pairs with sums equal to itself. $X_4$ = 2 x 3 x 5 = 30 [6], is equal to the sums of three different pairs of primes (Figure 2). For example, 7 and 23 constitute a prime pair that has a sum of 30. 23, a half of the pair, is connected with seven different even differences, including 4, 6, 10, 12, 16, 18, and 20 in Figure 2. Such connections imply that seven different even sums including 26, 24, 20, 18, 14, 12 and 10 can be obtained by replacing 23 with primes including 19, 17, 13, 11, 7, 5, and 3, respectively, while the other half of the pair, 7, remains static. In the meantime, 7, the other half of the pair, is connected with six different even differences, including 2, 4, 6, 10, 12, and 22. Such connections imply that six different even sums including 28, 34, 36, 40, 42, and 52 can be obtained by replacing 7 with primes including 5, 11, 13, 17, 19, and 29, respectively, while the other half of the pair, 23, remains static.

*Table 1:* The differences of primes 7 and 11 from greater primes in Figure 2 constitute a consecutive even array ranging from 2 to 12.

| Prime | Differences | Annotation |
|---|---|---|
| 7 | 4, 6, 10, 12, 16, 22 | interrupted array |
| 11 | 2, 6, 8, 12, 18 | interrupted array |
| Summary of all differences | 2, 4, 6, 8, 10, 12 | consecutive array |

The existence of such a consecutive even difference array ranging from 2 to 12 implies that every evens in [30, 42] can be expressed as sums of two primes in Figure 2, after re-pairing demonstrated in Figure 3.

*Table 2:* The differences of primes 23 and 19 from smaller primes in Figure 2 constitute a consecutive even array ranging from 2 to 20.

| Prime | Differences | Annotation |
|---|---|---|
| 23 | 4, 6, 10, 12, 16, 18, 20 | interrupted array |
| 19 | 2, 6, 8, 10, 12, 14 | interrupted array |
| Summary | 2, 4, 6, 8, 10, 12, 14, 16, 18, 20 | consecutive array |

The existence of such a consecutive array of even differences ranging from 2 to 20 implies that all evens in [10, 30] can be expressed as sums of two primes in Figure 2, through re-pairing demonstrated in Figure 3.

In summary, the above two observations prove that all evens in [10, 42] can be expressed as sums of two primes in Figure 2.

Case 2. When $X_n = 210$

$X_5 = 2 \times 3 \times 5 \times 7 = 210$, is equal to the sums of 19 different pairs of primes (Figure 4). For example, 11 and 199 constitute a prime pair that has a sum of 210. 199, a half of the pair, is connected with 41 different even differences ranging from 2 to 196 (the list is omitted for simplicity) (Table 3). Such connections imply that 41 different even sums ranging from 14 to 210 can be obtained by replacing 199 with other smaller primes in Figure 4, through re-pairing demonstrated in Figure 3. 11, the other half of the pair, is connected with 41 different even differences ranging from 2 to 188 (Table 4). Such connections imply again that, by replacing 11 with greater primes in Figure 4, 41 different even sums ranging from 212 to 398 can be obtained (the list is omitted for simplicity).

Analysis of the above cases suggests that an array of consecutive evens differences in certain range guarantees all evens within certain range centered on super product of a prime to be expressed as sums of at least one pair of primes through re-pairing demonstrated in Figure 3.

*Table 3:* Differences of seven primes from smaller primes in Figure 4. Differences of these primes from other primes in Figure 4 constitute a consecutive array of evens ranging from 2 to 196.

| Prime | Differences | |
|---|---|---|
| 199 | 2, 6, 8, 18, 20, 26, 32, 36, 42, 48, 50, 60, 62, 68, 72, 86, 90, 92, 96, 98, 102, 110, 116, 120, 126, 128, 132, 138, 140, 146, 152, 156, 158, 162, 168, 170, 176, 180, 182, 186, 188, 192, 194, 196 | interrupted array |
| 197 | 4, 6, 16, 18, 24, 30, 34, 40, 46, 48, 58, 60, 66, 70, 84, 88, 90, 94, 96, 100, 108, 114, 118, 124, 126, 130, 136, 138, 144, 150, 154, 156, 160, 166, 168, 174, 178, 180, 184, 186, 190, 192, 194 | interrupted array |
| 193 | 2, 12, 14, 20, 26, 30, 36, 42, 44, 54, 56, 62, 66, 80, 84, 86, 90, 92, 96, 104, 110, 114, 120, 122, 126, 132, 134, 140, 146, 150, 152, 156, 162, 164, 170, 174, 176, 180, 182, 186, 188, 190 | interrupted array |
| 191 | 10, 12, 18, 24, 28, 34, 40, 42, 52, 54, 60, 64, 78, 82, 84, 88, 90, 94, 102, 108, 112, 118, 120, 124, 130, 132, 138, 144, 148, 150, 154, 160, 162, 168, 172, 174, 178, 180, 184, 186, 188 | interrupted array |
| 181 | 2, 8, 14, 18, 24, 30, 32, 42, 44, 50, 54, 68, 72, 74, 78, 80, 84, 92, 98, 102, 108, 110, 114, 120, 122, 128, 134, 138, 140, 144, 150, 152, 158, 162, 164, 168, 170, 174, 176, 178 | interrupted array |
| 179 | 6, 12, 16, 22, 28, 30, 40, 42, 48, 52, 66, 70, 72, 76, 78, 82, 90, 96, 100, 106, 108, 112, 118, 120, 126, 132, 136, 138, 142, 148, 150, 156, 160, 162, 166, 168, 172, 174, 176 | interrupted array |
| 151 | 2, 12, 14, 20, 24, 38, 42, 44, 48, 50, 54, 62, 68, 72, 78, 80, 84, 90, 92, 98, 104, 108, 110, 114, 120, 122, 128, 132, 134, 138, 140, 144, 146, 148 | interrupted array |
| Summary of the above differences | 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, 144, 146, 148, 150, 152, 154, 156, 158, 160, 162, 164, 166, 168, 170, 172, 174, 176, 178, 180, 182, 184, 186, 188, 190, 192, 194, 196 | consecutive even differences |

The existence of such a consecutive even difference array ranging from 2 to 196 implies that all evens in [14, 210] can be expressed as sums of two primes in Figure 4.

*Table 4:* Differences of seven primes from greater primes in Figure 4. All the differences of these primes from other primes in Figure 4 constitute a consecutive array of evens ranging from 2 to 188.

| Prime | Differences | Annotation |
|---|---|---|
| 11 | 2, 6, 8, 12, 18, 20, 26, 30, 32, 36, 42, 48, 50, 56, 60, 62, 68, 72, 78, 86, 90, 92, 96, 98, 102, 116, 120, 126, 128, 138, 140, 146, 152, 156, 162, 168, 170, 180, 182, 186, 188 | interrupted array |
| 13 | 4, 6, 10, 16, 18, 24, 28, 30, 34, 40, 46, 48, 54, 58, 60, 66, 70, 76, 84, 88, 90, 94, 96, 100, 114, 118, 124, 126, 136, 138, 144, 150, 154, 160, 166, 168, 178, 180, 184, 186 | interrupted array |
| 17 | 2, 6, 12, 14, 20, 24, 26, 30, 36, 42, 44, 50, 54, 56, 62, 66, 72, 80, 84, 86, 90, 92, 96, 110, 114, 120, 122, 132, 134, 140, 146, 150, 156, 162, 164, 174, 176, 180, 182 | interrupted array |
| 19 | 4, 10, 12, 18, 22, 24, 28, 34, 40, 42, 48, 52, 54, 60, 64, 70, 78, 82, 84, 86, 90, 94, 108, 112, 118, 120, 130, 132, 138, 144, 148, 154, 160, 162, 172, 174, 178, 180 | interrupted array |
| 23 | 6, 8, 14, 18, 20, 24, 30, 36, 38, 44, 48, 50, 56, 60, 66, 74, 78, 80, 82, 86, 90, 104, 108, 114, 116, 126, 128, 134, 140, 144, 150, 156, 158, 168, 170, 174, 176 | interrupted array |
| 29 | 2, 8, 12, 14, 18, 24, 30, 32, 36, 42, 44, 50, 54, 60, 68, 72, 74, 76, 80, 84, 98, 102, 108, 110, 120, 122, 128, 134, 138, 144, 150, 152, 162, 164, 168, 170 | interrupted array |
| 31 | 6, 10, 12, 16, 22, 28, 30, 34, 40, 42, 48, 52, 58, 66, 70, 72, 74, 78, 82, 96, 100, 106, 108, 118, 120, 126, 132, 136, 142, 148, 150, 160, 162, 166, 168 | interrupted array |
| Summary of all above differences | 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96,98, 100, 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, 144, 146, 148, 150, 152, 154, 156, 158, 160, 162, 164, 166, 168, 170, 172, 174, 176, 178, 180, 182, 184, 186, 188 | **consecutive** array |

The existence of such a consecutive even difference array ranging from 2 to 188 implies that all evens in [210, 398] can be expressed as sums of two primes in the Figure 4.

In summary, all evens in [14, 398] can be expressed as sums of two primes in Figure 4.

## II. CASE SUMMARY

In the above analyses, existence of a consecutive array of even differences makes it possible for any evens within certain range centered on a super product of a prime to be expressed as sums of two primes. The premise for such a generalization is that as long as all even differences are related to at least one of paired primes. This guarantees all evens within a certain range centered on a super product of a prime to be expressed as sums of two primes, after repairing demonstrated in Figure 3. Such premise appears to be no challenge at all, as 2 primes are enough to generate such an array in case $X_4$ = 30 (Table 1-2) while 7 primes are enough to generate such an array in case of $X_5$ = 210 (Table 3-4). As super product increases expotentially, the number of prime pairs increases correspondingly, this makes re-pairing and generating more evens as sums of two primes easier. It is intriguing that the value of super product of primes increase into the infinite as primes do while the differences among primes are conservative and can be passed into the infinite, as shown in Figures 4-5 in [6]. It seems hard to find an upper limit for the applicable scope of the above generalization.

This completes proof 2 of Theorem 2.

A corollary can be inferred from Theorem 2. Namely,

Corollary 1: Every even number greater than 4 is equal to the sum of two primes.

Corollary 1 is an equivalent of Goldbach Conjecture.

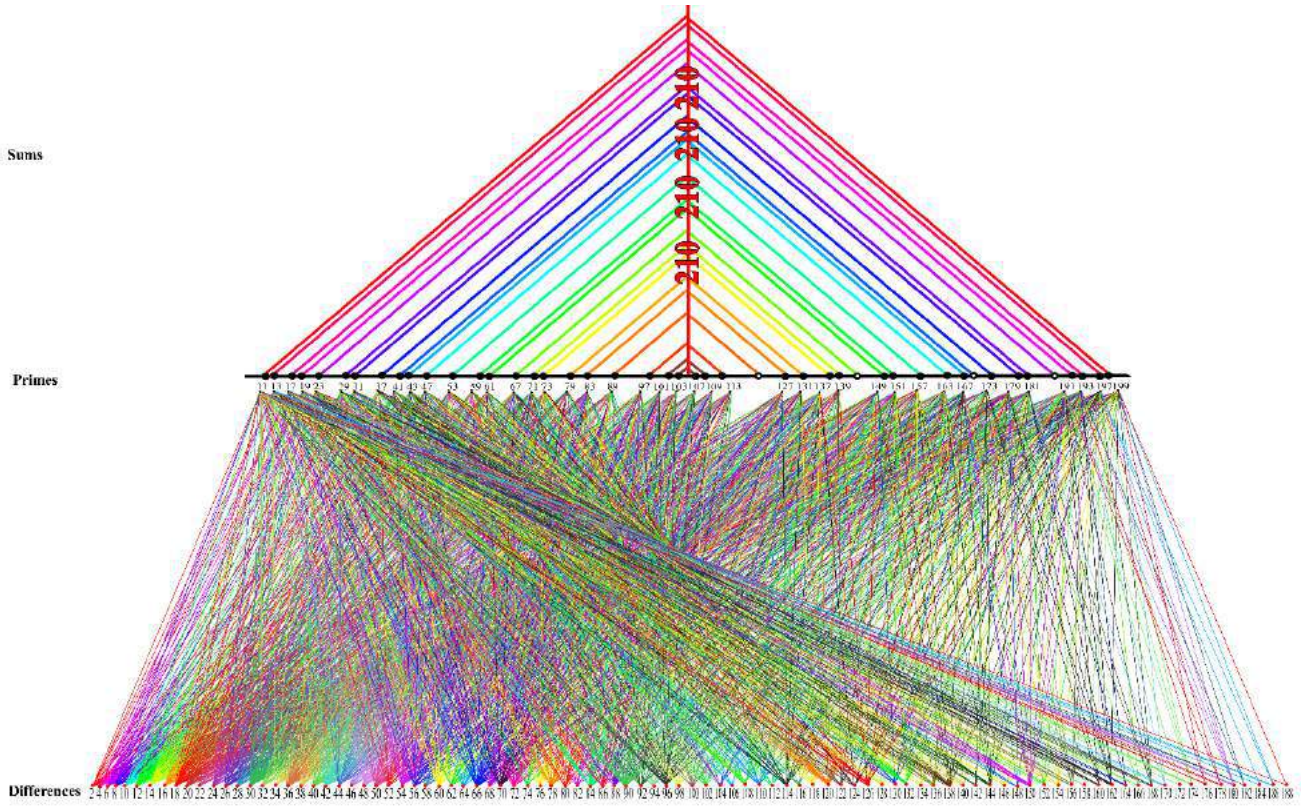


*Figure 4:* In the middle, odd primes smaller than 210 are plotted on an axis. Above the axis, 38 primes are paired and have sums equal to 210. Below the axis, even differences ranging from 2 to 188 are connected to their related primes.

## III. CONCLUSIONS

The Goldbach Conjecture is proven true. This will help to accelerate related research on primes.

## CONFLICTS OF INTERESTS

The author declares no conflicts of interests regarding the publication of this paper.

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# Damping Storms, Reducing Warming, and Capturing Carbon with Floating, Alkalizing, Reflective Glass Tiles

*Jeff T Haley & J Matthew Nicklas*

## ABSTRACT

Hurricane Harvey in 2017 caused $125 billion in damages in the U.S. (NOAA 2021). Could we spread reflective glass foam tiles on the north Atlantic gyre to cost-effectively reduce storm damage and reflect solar energy to space? The tiles might be made of sand from the Sahara desert with energy from photovoltaic panels. The tiles can be designed to slowly release an alkalizer to raise the pH of the water surface to increase absorbance of atmospheric $CO_2$ or release nutrients to promote growth of carbon-fixing organisms. The alkalizer and nutrients can be dissolved from fine grains of mineral adhered to the tile's bottom surface, avoiding the need for expensive extra-fine grinding of the mineral. Because the ability of oceans to absorb $CO_2$ will go down as ocean water gets warmer, reducing ocean heat gain with reflective floating tiles is synergistic with $CO_2$ absorption. Because surface currents in gyres converge toward the center, the half-life before washing onto beaches would likely be about three years, much longer if the tiles can be designed to have very low windage. Tiles washed onto beaches may be collected and redeployed. When they break and erode, the tiles revert to sand. Considering the benefits of reducing tropical storm damage, removing $CO_2$ from the atmosphere, and reflecting solar energy to space, deploying such tiles in the North Atlantic Gyre may be cost effective.

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# Damping Storms, Reducing Warming and Capturing Carbon with Floating, Alkalizing, Reflective Glass Tiles

Jeff T Haley[α] & J Matthew Nicklas[σ]

## ABSTRACT

*Hurricane Harvey in 2017 caused $125 billion in damages in the U.S. (NOAA 2021). Could we spread reflective glass foam tiles on the north Atlantic gyre to cost-effectively reduce storm damage and reflect solar energy to space? The tiles might be made of sand from the Sahara desert with energy from photovoltaic panels. The tiles can be designed to slowly release an alkalizer to raise the pH of the water surface to increase absorbance of atmospheric $CO_2$ or release nutrients to promote growth of carbon-fixing organisms. The alkalizer and nutrients can be dissolved from fine grains of mineral adhered to the tile's bottom surface, avoiding the need for expensive extra-fine grinding of the mineral. Because the ability of oceans to absorb $CO_2$ will go down as ocean water gets warmer, reducing ocean heat gain with reflective floating tiles is synergistic with $CO_2$ absorption. Because surface currents in gyres converge toward the center, the half-life before washing onto beaches would likely be about three years, much longer if the tiles can be designed to have very low windage. Tiles washed onto beaches may be collected and redeployed. When they break and erode, the tiles revert to sand. Considering the benefits of reducing tropical storm damage, removing $CO_2$ from the atmosphere, and reflecting solar energy to space, deploying such tiles in the North Atlantic Gyre may be cost effective.*

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## I. INTRODUCTION

Between 1980 and 2020, tropical cyclones (called hurricanes in north America) caused $997.3 billion in damages in the U.S., an average cost of $50 billion per year, and caused 6,593 deaths (Smith 2021).

In 2011, Seitz proposed reducing global warming and tropical storm intensity by making ocean surfaces more reflective with machine generated sea foam (Seitz 2011). Gabriel *et al* studied application of the foam in select regions and concluded this method could work (Gabriel et al. 2017). Unfortunately, no-one has found a way to make long-lasting sea foam without adding chemicals that are too expensive and would likely have deleterious side effects. Ortega and Evans analyzed the energy requirements and capital equipment requirements to make the foam with added surfactants and concluded that, if the duration of foam bubbles cannot be greatly increased, the method will not be cost effective (Ortega and Evans 2017). A potential alternative is to place floating, reflective glass foam tiles on ocean surfaces.

Kheshgi (1995) proposed enhancing ocean alkalinity by adding finely ground alkaline minerals such as ultramafic rocks (e.g. olivine) to oceans to raise surface pH and thereby increase absorbance of $CO_2$ into the oceans. Martin and Fitzwater (1988) proposed absorbing $CO_2$ into the ocean surface by fertilizing with iron to stimulate

phytoplankton growth in high-nutrient, low-chlorophyll waters where the growth limiting factor is availability of iron. Other ocean areas might be best fertilized with other metals, nitrogen, phosphorus, or silica (NASEM 2021). Each of these methods will be effective if the $CO_2$ is naturally incorporated near the surface into materials that sink to great depth in the ocean. The oceans have enough $CO_2$ storage capacity to hold all the excess $CO_2$ now in the atmosphere. Unfortunately, with modelling, Mongin et al. (2021) concluded that such materials spread on the ocean surface sink deep into the water column before they dissolve and will not be as effective as desired, reducing by more than half the amount of $CO_2$ that could be absorbed from the air if the particles stayed near the surface while they dissolve. Despite this inefficiency, the authors conclude that artificial ocean alkalinization can entirely offset the effects on the Great Barrier Reef of ocean acidification. Floating reflective glass foam tiles can release over time at the surface of the water nutrients or alkalizers from relatively large grains of mineral adhered to the bottom sides of tiles and fine grinding to about one micron size is not required (NASEM 2021).

The lowest cost solid material for making foam is silica sand ($SiO_2$) which can be made into foamed glass tiles. Grains of a slowly dissolving alkalizer or nutrient fertilizer can be adhered to the tiles to raise the nearby pH to increase absorption of $CO_2$ from the atmosphere and promote growth of $CO_2$ fixing organisms. The silica sand, alkalizer, and nutrients can be selected to be benign for the environment.

This article proposes experimenting with solar-reflective, long-lasting, floating glass foam tiles that release an alkalizer and/or nutrients and spreading them on oceans, particularly in gyres and up-current from coral reefs. The objectives are to:

1. Reduce absorbance of solar energy and reduce water temperatures to reduce tropical cyclone damage and reduce coral damage;
2. Increase absorbance of $CO_2$ from the atmosphere by maintaining high pH at the water surface over months and by reducing solar heat gain of the water;
3. Increase absorbance of $CO_2$ from the atmosphere by supplying at the surface nutrients to promote growth of organisms that fix carbon;
4. Reduce acidity to reduce suppression of coral growth when deployed up-current from coral reefs; and
5. Reduce the Earth's energy imbalance to reduce global warming by reflecting solar energy to space.

In December, 2021, the National Academies of Sciences, Engineering, and Medicine (NASEM 2021) published a comprehensive report reviewing and summarizing all research to date on nutrient fertilization and ocean alkalinity enhancement to increase absorbance and sequestration of $CO_2$ from the atmosphere and urging that further research be done, proceeding now to mesoscale experiments. The floating glass foam tiles can be used as a vehicle to deliver experimental nutrients and alkalizers and hold them at the water surface while they dissolve, achieving a greater effect than if the nutrients and alkalizers dissolve well below the surface and avoiding the expense of grinding the materials to one micron particle sizes.

## II. WHERE TO LAUNCH FLOATING REFLECTIVE TILES

A location for launching tiles where there would be benefits greater than merely the benefits for Earth's energy balance and atmospheric $CO_2$ reduction is the tropical North Atlantic Gyre (Figure 1) to also reduce hurricane damage. There are few beaches within the gyre that would receive substantial deposits of tiles, merely the small islands of Bermuda, Azores, Madeira, Selvagens, and Canary Islands. An industry of independent operators might gather tiles off beaches for redeployment in exchange for payment upon delivery.

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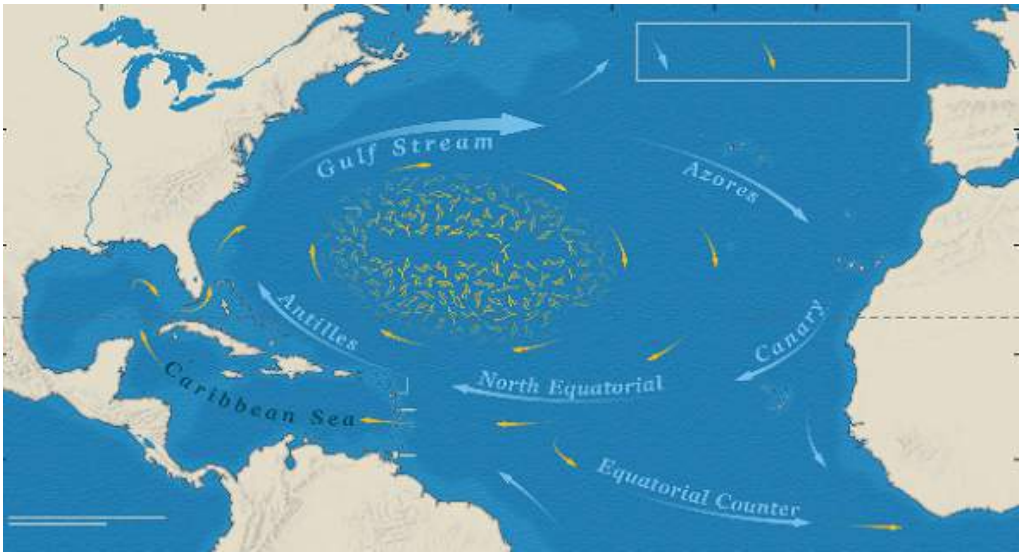


*Figure 1:* The North Atlantic Gyre showing where floating Sargassum seaweed is retained in the gyre

A factory could be located on a shore where there is a low cost supply of silica sand and electricity generated without burning fossil fuels. The best location might be the west end of the Sahara desert, such as in Mauritania or Western Sahara, where electricity could be generated with photovoltaic panels and silica sand is plentiful. The tiles would be loaded onto barges and dumped in the optimal location within the gyre, which might be near the northwest Africa coast to minimize transportation costs.

Cogley (1979) reports that mean albedo of waters of the North Atlantic Gyre is about 5-9%, presenting an opportunity for about 80% gain in solar reflectivity from highly reflective tiles. Reducing heat gain of the North Atlantic Gyre water under tiles by 80% will reduce strength of hurricanes in North America and reduce coral damage. It will also enhance the ability of surface water to absorb $CO_2$ by increasing solubility of $CO_2$ in the water (NASEM 2021). If the absorbed $CO_2$ is well fixed near the surface, currents of the gyre will carry the fixed $CO_2$ toward the center of the gyre and then downward, accelerating decent to a preferred depth. Considering the high cost of tropical cyclone damage in the North Atlantic, the benefits of removing $CO_2$ from the atmosphere, the benefits of reflecting solar energy to space, and the relative lack of beaches in the North Atlantic Gyre where tiles would wash up shortly after launch, launching huge quantities of such tiles at an optimal location in the North Atlantic Gyre (Figure 1) may be cost-effective.

## III. TARGET DESIGN TO ACCOMMODATE ORGANIC GROWTH

Due to Coriolis effect, ocean gyres have surface currents that converge toward their centers and then sink (downwelling). Floating objects with low windage (how much the surface wind moves the tiles relative to the surface water), such as Sargassum seaweed in the North Atlantic Gyre and human trash, often remain floating at gyre centers for many years or decades, forming what are sometimes called garbage patches. The most crucial issue for design of the tiles and research on feasibility and cost effectiveness is the problem of organic growth on tiles that would cause them to sink (Kaiser et al. 2017). This may require that the tiles start with high windage. The tiles should protrude above the surface of the water enough to remain reflective white on top rather than covered with organic growth, but, to minimize windage and thereby extend the average length of time before washing onto a beach, they should protrude no more than necessary. Thus, the buoyancy of the tiles would ideally increase at the same rate that organic growth decreases total buoyancy so the windage constantly remains optimally low. Buoyancy of the tiles can be designed to increase over time by adhering to the tiles slowly dissolving/ablating alkalizer or

nutrient grains heavier than water. And, by slowly ablating, the grains may cause shedding of organic growth to extend the time until biofouling causes tiles to sink. The next steps for researching whether the tiles will be effective is to determine how high a flat top object must float above the sea water surface to not grow seaweed on top and how high it must start to not be pulled below that level by weight of growth over the target lifetime; then determine the windage of this design.

For a starting estimate of windage, Novelli et al. measured the windage of toroidal drift trackers that protruded 3 cm out of sea water (Novelli 2017). Most of the drift trackers had drogues but some were released without drogues. Off the coast of Florida, the trackers without drogues had a measured actual windage of 2%, which suggests that the tiles will have a windage of 2% or less. Protruding 3 cm out of the water surface is likely much more than is needed to prevent growth of seaweed on top.

## IV. EXPECTED HALF-LIFE BEFORE WASHING UP ON A BEACH

In a particular gyre, the stronger the surface current toward the center, the greater the windage the current can overcome to keep the tiles from washing up on a beach at the edge of the gyre. Sargassum floating seaweed is retained by centering currents in the North Atlantic Gyre indefinitely. No such seaweed has been reported in the North Pacific Gyre. Therefore, we assume that the centering currents in the North Atlantic Gyre are at least as strong as the centering currents in the North Pacific Gyre, and we assume that tiles would remain in the North Atlantic Gyre at least as long as they would remain in the North Pacific Gyre. Models of drift by floating objects and data from the North Pacific Gyre that has been used to refine the models give us a rough estimate of likely half-life for tiles in the North Atlantic Gyre.

Maximenko et al. gathered data from debris washed into the Pacific ocean by the Great Japan Tsunami of 2011 to compare with predictions of five models of movement of floating objects across the North Pacific Gyre (Maximenko 2018). In all the models, debris with a windage higher than about 3% (meaning the velocity of drift is 3% of the wind velocity added to the velocity of the surface water) was blown past the gyre by prevailing westerly winds and landed on beaches of North America, while debris with windage lower than about 3% turned with the gyre current toward the center of the gyre and experienced a much longer half-life before leaving the gyre. Of the objects that made the first turn into the gyre, most having windage lower than 3%, the average prediction of models was that those objects would experience a half-life of 3.4 years before leaving the gyre (e-folding duration of 4.85 years). Maximenko et al. compared the various model results and found all the models gave relatively consistent results for objects with 2% windage. The model results had the highest agreement with data from floating objects at windages ranging from 1.1% to 2.8%.

If the proposed tiles have windage higher than 3%, the Maximenko data for the North Pacific Gyre suggests that more than half will likely be blown out of the North Atlantic Gyre within a year. If the windage is about 2% as suggested by the Novelli data, the Maximenko data suggests that the half life duration in the North Atlantic Gyre will likely be about 3 years.

## V. MAKING FLOATING GLASS TILES

Tiles can be made with a foam of closed-cell gas bubbles. Target formulation, density, and tile thickness may be selected to (a) float on sea water over a target lifespan, (b) release an alkalizer or nutrient at an optimal rate, and (c) optimize solar reflectivity, absorption of $CO_2$, environmental effects, and cost. Ingredients that might make the tiles toxic, such as lead, mercury, asbestos, and perhaps nickel, can be avoided. Energy to make glass foam tiles can be generated from carbon-free sources such as photovoltaic panels. Tile material may be made in large slabs and cut or broken to dimensions at least five times greater than the thickness.

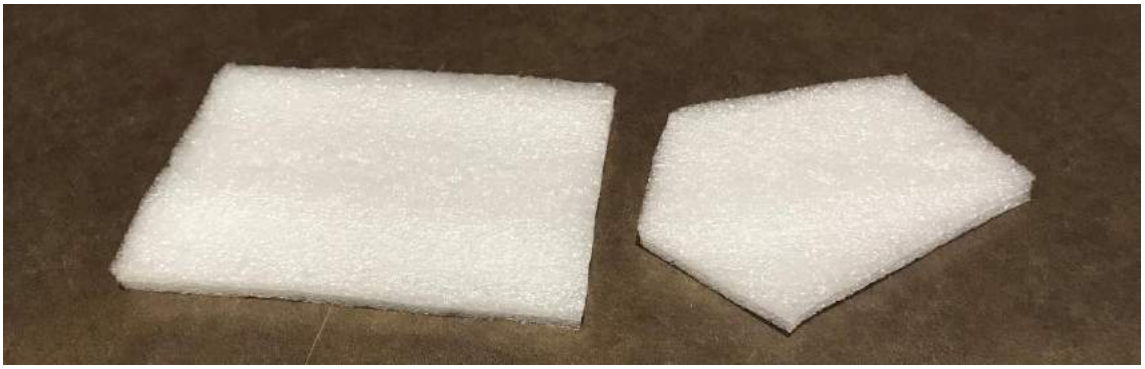

*Figure 2:* Models of glass foam tiles

### *5.1 Making solar reflective glass tiles with a density lower than water*

Following Mie theory, transparent material such as glass can be made highly solar reflective by forming alternating pockets of air and glass where the air pockets and glass pockets each have average diameters of roughly one micron. This is why snow and clouds are white. Larger air pocket sizes are also highly effective. The density of solid glass is about 2.5 times that of water. To make tiles that will float on ocean water (Figure 2), the tiles must, by volume, be no more than 40% glass and at least 60% gas with an internal pressure about the same as atmospheric pressure at sea level. Work by Wang et al. (2021) with transparent polymer having pores of .2 microns to 5 microns shows that 95% solar reflectivity is achievable with 60% porosity. Haley (2021) reports a solar reflectivity of 95% in Entek polyethylene film open cell foam with pore sizes from .05 to 1 micron. Ninety-five percent solar reflectivity is likely the upper limit of what can be achieved with glass foam. To float high enough that they will not sink from the weight of alkalizer and nutrient or biofouling within the target lifetime, the tiles may need to be up to 80% gas.

### *5.2 Present commercial method of making glass foam*

Technology to make foamed glass with bubbles of 10 to 300 microns is well known and used to make inert heat insulating material such as for a concrete additive (Dennert Poraver 2001) or an insulating lower layer under road pavement to prevent frost heaves (Figure 3) (Segui et al. 2016).

*Figure 3:* Chunks of glass foam for insulation under roads

To make the foam, particles of glass and particles of a chemical gas generating agent are mixed, placed in a furnace, and heated to around 800-900°C to obtain the viscoelastic state of glass. This temperature causes the chemical agent to release a gas, forming bubbles in the glass, and the mixture is then formed into a desired shape and cooled. While it is cooling, it may be cut to desired shapes and sizes when partially hardened. Using current manufacturing methods, the resulting foam density (relative to pure water) ranges from .3 to .9. A detailed article on making foam glass is linked in the references (Scarinci et al. 2005).

This technology can be adapted to make highly reflective tiles by using very small particles of both glass and the gas forming agent. Particles of preferred sizes have average diameters in the range of 50 nanometers to two microns, made by pulverizing such as with a ball mill. Larger sizes are likely also effective. Using very small particles results in smaller bubble sizes provided the mixture is not heated to a point of low enough viscosity that the bubbles rise upward or merge together.

### *5.3 Making glass foam under pressure*

Instead of adding a gas forming agent, using a method invented by Willis (1941), ground particles of glass with pockets of air in the interstitial cracks can be pressurized to increase the amount of gas in the interstices, then heated until the glass melts to surround all air pockets but still has a high viscosity, then depressurized so the air bubbles expand to at least 60% of the volume, and then cooled in a sheet. The resulting material can be broken or cut to suitable sizes.

### *5.4 Tiles made by syntactic aggregation of glass microspheres*

Technology has been known for more than 50 years for making individual glass microspheres (a/k/a bubbles or microballoons) as small as 5 microns diameter (Koopman et al. 2004) with a density (relative to pure water) ranging from .1 to .6 (3M Corp 2007). The process might be modified to make microspheres with an average diameter of one to five microns. Suitably large tiles with a density less than 1 may be made by gluing together such microspheres to make tiles of syntactic foam (Ramadin et al. 1996). The glue might be liquid sodium silicate glass (water glass) with a slow rate of dissolution or Type I poly-vinyl-acetate (PVA). The mix is poured into a slab and the water is evaporated to make solid tiles. With this formulation, as the tiles slowly disintegrate, microspheres that are released will float and continue to maintain a higher albedo at the water surface.

## VI. COATING THE TILES WITH A SLOWLY RELEASED ALKALIZER

Alkalizers that might be adhered to the tiles include mineable magnesium or calcium silicate minerals such as wollastonite, olivine, anorthite, brucite, portlandite, forsterite, and peridotite or carbonate minerals such as, calcite (chalk or limestone) and dolomite (Renforth and Henderson 2017, NASEM 2021). The minerals could include iron, which is common in olivine rocks, or other nutrients (NASEM 2021). The preferred method of adhesion is to apply hot mineral grains to hot tiles before they finish cooling where the mineral grains are hot enough to melt the glass surface which adheres them strongly as it cools. The size of the grains should be selected to take more than two half lives (likely 6 years) to finish dissolving in seawater. The tiles can be launched with the mineral grains side down. If the tiles are turned over by wind and waves or ship collisions, most of them will end up grainy side down because it is more dense than the glass foam. To facilitate the tiles righting themselves when turned over by wind, the tiles can be cut long and narrow. (Figure 4).

*Figure 4:* Long and narrow tiles with mineral grains adhered on one side

Instead of adhering mineral grains by melting the surface of the glass foam, grains can be adhered with a slowly dissolving water soluble glass silicate of an alkali metal, (sodium, potassium, or lithium), preferably sodium, traditionally called water glass or soda glass (sodium silicate). Soda glass slowly dissolves releasing sodium oxide ($Na_2O$) which, in water, forms sodium hydroxide (NaOH, lye, $Na_2O + H_2O \rightarrow 2\ NaOH$), a strong base, which is a favored absorbent for capture of carbon dioxide (Cambier 2017, Stolaroff et al. 2008). The glass foam itself might be made with soda glass. Douglas and El-Shamy (1967) report a suitably slow enough rate of dissolution for some formulations of soda glass.

If minerals are adhered with alkali silicate, the minerals can be ground to roughly one micron particle size to maintain high Mie scattering solar reflectivity so the tile is still highly reflective if it turns over. Calcium carbonate particles with an average cross-section diameter of about .5 microns used as pigment in an acrylic paint achieve a solar reflectivity of 95.5% (Li et al. 2020). The adhesion process might involve coating a sheet of glass foam with liquid adhesive and then dusting on a layer of powder. Figure 4 shows foam glass beads coated with calcium carbonate powder made by applying liquid poly-vinyl-acetate glue, dusting with chalk powder, and drying (Figure 5).

*Figure 5:* AGSCO (Wheeling Illinois) glass foam beads coated with adhered chalk dust

Like marine buoys, the tiles might be designed to have low enough density after all alkalizer and adhesive are dissolved that the tiles will keep floating despite the maximum amount of growth within the designed life of the tiles. Up to that point, the release of alkalizer to raise local pH is expected to reduce organic growth on the tiles (Qin 2015).

## VII. POTENTIAL RISKS TO BE INVESTIGATED

### *7.1 The tiles will reduce photosynthesis*

Reflecting solar radiation will reduced growth of phyto-organisms, reducing strength of the biological sinking of carbon into deep water (NASEM 2021). Studies should be undertaken to estimate whether this detriment outweighs reducing tropical cyclone damage, increasing removal of CO2 from the atmosphere, reducing Earth's energy imbalance, and reducing heat and acid damage to coral reefs.

### *7.2 Termination shock*

If the tiles are applied every year as the climate grows hotter, the tiles will limit adaptation by corals and, if application is then skipped one year, the corals may experience a fatal shock. Before commencing extensive deployment, we should be confident this method can be continued until the method can be slowly reduced in density to let corals slowly adapt.

### *7.3 Tiles high on beaches might reduce beach values*

The tiles would build up as a new form of very white jetsam on some beaches and take time to crumble into fine sand. Some people might view this as pollution. Machines or low cost labor could groom the beach by picking up tiles to relaunch them on the sea.

### *7.4 Tiles on beaches may harm beach life*

Tiles on beaches may be designed to slowly leach sodium oxide and form lye with rain water as they crumble into fine sand. Close to each tile, the lye may be concentrated enough to harm beach organisms.

### *7.5 Fish might eat so many tiles that they suffer adverse effects*

The affected fish may adapt and stop eating the tiles.

### *7.6 Tiles on a beach might blow in wind*

The tiles should be made high enough density and suitable shapes to prevent blowing in a common wind after washing up on a beach.

### *7.7 Mining sand and alkaline/nutrient rocks*

Mining on land may cause local pollution and $CO_2$ emissions.

## VIII. CONCLUSION

Considering potential benefits of reducing tropical cyclone damage, removing atmospheric $CO_2$, and reducing Earth's energy imbalance, the proposed method deserves further investigation. The next steps are to determine how high a tile must float above the sea water surface to not grow seaweed on top and how high it must start to not be pulled below that level by weight of growth over the target lifetime; then determine the windage of this design. Experiments should be conducted to determine likely optimal tile density, thickness, alkalizer/nutrient type and and grain size, then determine extent of toxic effects, and show that the tiles last a cost-effective duration and are not made ineffective by organic growth. Nutrient concentration and pH in ocean water around floating prototype tiles should be measured to estimate amounts of $CO_2$ that will be absorbed from the atmosphere. Effects of tiles should be modeled to estimate minimum numbers to obtain adequately scaled benefits. Ways of making and deploying tiles should be investigated and projected costs tallied for cost-benefit analysis assuming a factory large enough to obtain economies of scale. The National Academies report (NASEM 2021) provides a detailed recommendation for further research on nutrient fertilization and alkalinity enhancement and urges mesoscale experiments as the next step (NASEM 2021). The use of floating reflective glass foam tiles to deliver the nutrients and alkalizers should be incorporated into those experiments.

*Authors' contributions:* All JTH except JMN contributed to estimate of windage and half life of floating tiles

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# Examination of the Views of Teachers Teaching Science in Primary Education on Science, Technology, Engineering and Mathematics (STEM) Education

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## ABSTRACT

In this study, the opinions of teachers providing science education about the Science-Technology-Engineering and Mathematics (STEM) education approach were examined. The research was carried out using the case study pattern. STEM Education Interview Form was used to determine the opinions of teachers who give science education about STEM education. The data of the research were evaluated by the qualitative content analysis method. According to the results of the research, it was understood that the teachers delivering science education did not have difficulty in associating science and mathematics with each other in the integrated science teaching process, which includes science, technology, mathematics, and engineering. However, results were obtained indicating that teachers had difficulty integrating technology and engineering disciplines and designing this education inappropriate science. Suggestions were made in light of the research results.

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# Examination of the Views of Teachers Teaching Science in Primary Education on Science, Technology, Engineering and Mathematics (STEM) Education

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## I. INTRODUCTION

The advances in science, and technology have gained great momentum in the 21st century especially affecting almost all areas of contemporary life. These advances have created some problems in the globalizing world, and the integration of science, technology, engineering, and mathematics disciplines has been required to solve these problems (Moore et al., 2014). As a natural result of integrating the aforementioned disciplines, the concept of STEM came to the agenda. STEM is a holistic concept that is the intersection of the disciplines it contains (Eroğlu and Bektaş, 2016). In the field of education, this intersection or integration of these disciplines has emerged from the initials of the words 'science', 'technology', 'engineering', and 'mathematics' in English - the concept of 'STEM education.' It has appeared as a new educational approach in the form of 'FeTeMM education' consisting of initials of the Turkish words for Science, Technology Engineering, and Mathematics. STEM education approach has been rapidly adopted in schools in both developed and developing countries and is rapidly becoming widespread. With the fast adoption of STEM education in schools, teachers and students can improve themselves in several areas (physical, cultural, social) and increase their self-efficacy towards gaining a critical structure and solving their problems more easily (Çorlu and Aydın, 2016). In addition, STEM education brings different disciplines together and provides multi-dimensional learning with an inter-disciplinary approach (Smith and Karr-Kidwell, 2000). As one of the answers to the question what is STEM education?, it can be briefly explained that STEM education enables students to blend interdisciplinary knowledge and integrate them to find solutions to the problems they face. It should also be remembered that preparing the future that the 21st-century economy has built will be realized with the solution-oriented learning

activities of students. In this context, the STEM education approach is important in gaining the 21st-century skills of students as individuals of the future (Aydeniz, 2017). Because it is very important for STEM education to raise qualified individuals to produce innovations that will provide an economic advantage for countries and keep up with what the era is bringing, and not fall behind the developments (Eroğlu and Bektaş, 2016).

It is seen that the aims of STEM education are compatible with these skills. These objectives can be broadly listed as follows (Thomas, 2014):

- To create a workforce consisting of people with STEM literacy.
- To continue the current operation in the field of STEM.
- To be able to produce innovations that will provide an economic advantage for countries.
- To be sufficient in future business areas.

As a vision of science education, the STEM education approach is important for science literacy (Miaoulis, 2009) to train experts and engineers who will interpret scientific and technological innovations. For this reason, STEM education should be integrated into the education system to develop the national economy and lead science and technology (Lacey and Wright, 2009). It is also known that receiving this integrated education at a young age has contributed to the orientation of individuals to these disciplines in the following years (National Research Council [NRC], 2011), and they have been able to apply what they have learned to the new situations they encounter (Morrison, 2006). Providing STEM education in schools and increasing the number of students who have received this education play an important role in gaining science literacy, achieving the future progress goals of countries in general, creating employment in industry, and increasing education. However, the realizing of qualified STEM education is related to the fact that teachers receive adequate and qualified STEM education (Wang, 2012). In this context, one of the important steps is to refer to the views of teachers on STEM education. As Wang (2012) stated, STEM education-based programs can make sense with qualified teachers, so it is important to determine what the situation is by referring to the opinions of teachers for qualified education.

When the literature is analyzed, it is seen that studies about STEM education are carried out in several countries. For example, in Turkey, it is seen that studies are conducted about STEM but remain limited in number (Baran, Canbazoğlu and Mesutoğlu, 2015; Karahan and Canbazoğlu 2014; Sahin, Ayar and Adıgüzel 2014; Yamak, Bulut and Dundar, 2014). Another point that draws attention among these studies of the countries is that the researches about how the STEM program should be shaped and how the teachers will implement the programs have been limited (Dugger, 2011). Likewise, it has been observed that the studies about STEM in the Turkish Republic of Northern Cyprus (TRNC) are very few, and the views of teachers who deliver science education about STEM, which is a current education approach, have not been examined.

This study, it is aimed to determine the views of teachers who give science education in TRNC about STEM education. For this purpose, answers to the following research question were sought.

- What are the opinions of teachers who give science education about STEM education?

## II. METHOD

### *2.1 Research Model*

The research was carried out using the case study pattern. A case study is defined as a method in which one or more events, environments, programs, social groups, or other interconnected systems are examined in depth (McMillan, 2000). The case study method was chosen to reveal in detail the opinions of teachers who deliver science education about science, technology, mathematics, and engineering (STEM). The case examined in the research is the opinions of teachers who deliver science education about integrating science, technology, mathematics, and engineering. In the study, the internal case study pattern, one of the case study patterns, was used. In this pattern, the situation itself is focused on

because the case is unusual or unique (Creswell, 2016). In the study, the realization of teaching by integrating science, technology, mathematics, and engineering has been determined as the case itself and has been handled as a whole.

### 2.2 Study Group

The universe of the research is the teachers who work in public and private primary schools in TRNC in the 2017-2018 academic year and provide science education. Due to the limited access to the universe group, a sample was selected using a convenience sampling method. The sample group consists of science education teachers of a private school chosen according to the convenience sampling method. Within the framework of the volunteering principle, ten teachers providing science education participated in the study and formed the sample group. Information on the demographic characteristics of the teachers participating in the research is given in Table 1.

*Table 1:* Demographic characteristics of teachers participating in the research

| Independent variables | Groups | f | % |
|---|---|---|---|
| Gender | Female | 6 | %60 |
| | Male | 4 | %40 |
| Age | 21-30 | 5 | %50 |
| | 31-40 | 3 | %30 |
| | 41-50 | 2 | %20 |
| Seniority | 0-5 | 4 | %40 |
| | 6-10 | 3 | %30 |
| | 11-15 | 3 | %30 |
| Education Status | Undergraduate | 7 | %70 |
| | Master | 3 | %30 |

Of the 10 participants who participated in the study, 6 (60%) were women, and 4 (40%) were men. Also, 5 (50%) of the teachers who constitute the study group of the research are between the ages of 21-30, 3 (30%) are between the ages of 31-40, and 2 (20%) are between the ages of 41-50. Four participants (40%) have 0-5 years of professional experience, 3 (30%) have 6-10 years of professional experience, and 3 (30%) have 11-15 years of professional experience. It can be said that most of the teachers participating in the research are new graduates. Seven (70%) of the teachers delivering science education who participated in the research have undergraduate education, and 3 (30%) have graduate education.

### 2.3 Data Collection Tools

In the research, STEM Education Interview Form was used to determine the opinions of teachers about STEM education who delivered science education. The STEM Education Interview Form used in the research was prepared by Yıldırım (2017). During the preparation phase, a review was done by a faculty member and two research assistants to check the extent to which the purposefulness, comprehensibility, and applicability of the STEM Education Interview Form. As a result of the feedback of these academicians a form was arranged. A form consisting of 10 problems was obtained by implementing a pilot application with three teachers who provided science education.

### 2.4 Collection of Data

Interviews were conducted with teachers using the interview form to obtain their views on STEM education. In this context, questions that teachers have on their minds, if any, were answered by the

researchers before to the interview. Before starting the interviews, an interview protocol was read to the teachers, and a voice recorder was used with the permission of the interviewed teachers to prevent possible loss of data in the recording of their data. In addition, the note-taking technique was used where necessary. During the interviews, which lasted for an average of 40 minutes, all participants were allowed the use of voice recorders.

For the interviews to be held with the teachers who delivered science education, the interview hours were determined beforehand. The interviews were held face-to-face in a quiet room at the school where the researchers conducted the study. The teachers were informed in advance about the meeting to be held. The teachers interviewed were selected according to the principle of volunteering.

### *2.5 Analysis of Data*

Findings obtained from semi-structured interviews with teachers providing science education were subjected to content analysis.

In content analysis, which aims to teach the concepts and relationships that can explain the collected data, the similarities of the data are determined and brought together within the framework of certain concepts and themes. In the coding phase, which is the first stage of content analysis, the data obtained are examined, tried to divide into meaningful sections, and what each section expresses conceptually is determined. After the codes are identified, the themes that can collect the codes under certain categories should be determined (Yıldırım & Şimşek, 2016). Categories are conceptual elements that cover several unique examples and relate to each other. Some of the basic categories can become sub-categories during content analysis. The names of the created categories can be based on the researcher, participant or literature (Merriam, 2015). These stages were followed in the content analysis conducted in this research.

Before analyzing the qualitative data obtained from the research, semi-structured interview data was transcribed first. The transcripted interview texts were presented to the teachers interviewed. The necessary changes were made on the interview text by asking whether the data in the transcript reflected their views and whether there is anything they wanted to add (confirmation of the participant). In addition, during the presentation of the transcripts of the interviews, the questions regarding the answers that were not clearly understood / comprehended by the researcher during the interviews with the teachers were asked once again. The data obtained from the interviews were tried to be validated. Codes, categories, and in some questions, sub-categories were created for each question by evaluating the opinions of the teachers. The data obtained from the interviews were then digitized by making them expressible as frequencies. Digitization was made to perform comparison between categories (Yıldırım & Şimşek, 2016). Findings from the interview data are presented in tables and interpreted.

Names of persons are not given in the text considering ethical factors in presentating the interview data (Ford & Reutter, 1990). Direct quotations of the answers of the teachers selected from the scale participants and coded as Ö1, Ö2, Ö3, Ö4, Ö5, Ö6, Ö7, Ö8, Ö9, Ö10 are included.

### *2.6 Validity and Reliability*

In this study, the strategies proposed by Erlandson, Harris, Skipper and Allen, 1993 (cited in Yıldırım & Şimşek, 2016) were used to minimize or eliminate factors that affect/threaten validity and reliability.

First of all, to increase the internal validity (credibility) of the study, as the negotiation time progressed, the time limit was not restricted in order to ensure a trusting environment and more sincere answers, and a long-term interaction was attempted. In addition, to obtain stronger data from the same teachers to reflect the truth, a contribution was made to the long-term interaction by conducting interviews for the necessary questions (long-term interaction). On the other hand, the results obtained from the interviews were supported by the findings obtained from other studies in the literature, and

effort was paid to increase the credibility of the research. As another measure taken within the scope of internal validity, expert opinions were used during the preparation of interview questions, analysis of the data and, the study process (expert review). In addition, the transcripts obtained from the interviews were checked by the interviewed teachers, and corrections were made where necessary (confirmation). Furthermore, within the scope of external validity (transferability), direct quotations are included (detailed description) to enable the data to be described in more detail.

To increase the internal reliability (consistency) of the study, questions were asked in the collection of data based on the interview form and using a voice recorder with a similar approach. In addition, the categories and codes obtained from the interviews were checked twice by the researchers one week apart.

Miles and Huberman (1994) refer to converging codes as 'Agreement' and diverging codes as 'Disagreement' and suggest the formula of Agreement Percentage = Agreement / (Agreement + Disagreement) * 100 for coding reliability. The fact that Miles-Huberman reliability formula value is above 70% shows that their coding is reliable (Akay and Ültanır, 2010). The coders' consideration of sub-problems and their orientation towards theme-oriented coding increased the 'percentage of agreement between coders. In qualitative data analysis, the level of cohesion between encoders is evaluated as an indicator of coding reliability. Therefore, it was interpreted as a high level of agreement among coders. Converging codes in the study are identified as 89, diverging codes were identified as 22, and agreement percentage was found as 80%. The percentage of agreement above 70% indicates that there is a high level of consensus among coders.

## III. FINDINGS

### *3.1 Findings Related to the Views of Teachers Regarding STEM Education Providing Science Education*

#### *3.1.1 The relationship between science course and technology and mathematics*

In the first question of the interview, the following question was asked to the teachers: "Is there a relationship between science lessons and mathematics and technology? If there is a relationship, what is it?" The categories and codes created according to the answers obtained are shown in Table 2.

*Table 2:* Teachers' thoughts on Science's relationship with Technology and Mathematics

| The relationship between science and Technology and Mathematics | Frequency |
|---|---|
| Integrity with each other | 9 |
| Using Mathematics and Technology in question solutions / operations | 6 |
| Using Mathematics and Technology in experiments | 4 |
| Contributing to his learning | 3 |
| Learning by doing and living | 2 |
| Embody what has been learned | 2 |

All the teachers interviewed underlined the relationship between science, technology, and mathematics. As can be seen in Table 2, the majority of teachers (f: 9) stated that science and technology and mathematics are integrated.

The teacher named Ö1 expressed his thoughts as follows: *"There is a connection between each other... Speed problems in science come to my mind. For example, it is necessary to multiply speed and time to calculate the distance a vehicle travels at a certain time. We need to do*

*mathematical operations to do this operation. I think the same is true in the relationship between science and technology. We have several technologies that we use in our daily lives, such as internet-connected smart boards, mobile phones, tablets, and computers in the classroom. These technologies have taken their current form thanks to the science of mathematics. So, these three concepts are interconnected".*

The teacher with the code Ö10 put forward his thoughts as follows: "*Of course there is. Today, technology and all disciplines should be combined and given in integrity. In science lessons, mathematical data is often used when expressing experimental results. Using technology, both lessons can be taught, and students can do research using technology and access information in an easy way*".

The Ö3 coded teacher put forward his opinions as follows: "*Of course there is a relationship, science is already a lesson in our lives, it is an integral part of our lives. For example, even technological tools and equipment such as microscopes, telescopes, magnifiers that we use in experiments are designed according to the rules of physics and mathematics, and work according to the information there.... To solve a problem in physics-related issues in science, we need mathematics, so they are intertwined*".

The teacher named Ö4 expressed his thoughts as follows: "*All three are interrelated. Because to comprehend science, mathematical operations must be known, and mathematics and science are used to reveal something new in technology".*

### *3.1.2 Opinions of teachers on engineering skills*

In the second question of the interview, the teachers were asked the question "What do you think about engineering skills? Have you ever heard of this concept?" and the categories and codes created according to the answers obtained are shown in Table 3.

*Table 3:* Teachers' thoughts on Engineering skills

| Thoughts on Engineering skills | Frequency |
|---|---|
| Design | 10 |
| Improving psychomotor skills | 8 |
| Product reveal | 7 |
| Making an Invention (Creating an Original Invention) | 7 |
| Improving your imagination | 5 |
| Revealing creativity skills | 4 |
| Improving problem-solving skills | 4 |
| Developing critical thinking skills | 3 |
| Uncovering digital intelligence | 2 |
| Using Technology effectively | 2 |
| Measuring | 1 |
| Require experimental material knowledge | 1 |

As shown in Table 3, the thoughts about engineering skills of all teachers (f: 10) were gathered under the category of 'designing'. In addition, most of the teachers stated that their engineering skills improve the psychomotor skills of students (f: 8), that they provide students with the opportunity to produce products (f: 7) and make inventions (f: 7). Half of the teachers stated that their engineering skills improved the imagination of students. In addition, teachers found that engineering skills reveal students' creativity (f: 4), problem-solving (f: 4) and critical

thinking (f: 3) skills, reveal their numerical intelligence (f: 2), and their ability to use technology effectively (f: 2), and stated that it allows them to make measurements (f: 1) and that they should have knowledge about experimental materials (f: 1). Sample quotations from the answers obtained from the second question of the interview are given below.

*'Engineering is a profession that requires talent. Psychomotor skills and numerical intelligence should also be prioritized in this profession. If there is no talent, they cannot be a successful engineer. '(Ö2)*

*'Engineering skills are the ability to think like an engineer. In science courses, especially students who want to choose the engineering profession in the future should be taught. I have not heard of this concept in my professional life before, but I have heard it during my graduate studies. '(S5)*

### *3.1.3 Gaining engineering and design skills in science class*

In the third question of the interview, the following question was asked to the teachers: "Can science and engineering skills be taught in the science course? How can this be achieved if it can be gained?" The data obtained from the third question of the interview are given in Table 4.

*Table 4:* Teachers' thoughts on whether Engineering and design skills can be gained during Science lesson teaching process

| To gain Engineering skills in Science class | Frequency |
|---|---|
| May gain | 9 |
| In activities related to experiment and material design | 8 |
| With the realization of teaching by doing and living | 7 |
| In teaching situations where creativity is at the forefront | 5 |
| In experiments requiring group work | 3 |
| By doing projects related to students' daily lives | 3 |
| By making more use of Technology in the teaching process | 2 |
| Paying attention to individual differences in teaching | 2 |
| Be endowed | 3 |
| The low accessibility and implementation in schools with low economic level | 2 |
| Due to the realization of subject-centered education | 1 |
| Teachers' inadequacies on this subject | 1 |

As can be seen in Table 4, the majority of teachers stated different reasons and said that they thought that their engineering skills could be gained during the science lesson teaching process. Teachers argued that students could gain engineering skills by conducting activities related to experimental and material design (8 teachers), realizing teaching by doing-living (7 teachers), and in teaching situations where creativity was at the forefront (5 teachers). On the other hand, 3 of the teachers argued that their engineering skills could not be transferred to students because of the difficulty of transferring engineering skills to students in schools with low economic levels (2 teachers), the realization of subject-centered teaching (1 teacher), and the teachers' inability to

transfer engineering skills to students (1 teacher). Sample quotations from the answers obtained from the third question of the interview are given below.

*"Today, students need to be developed most in these areas because if they are creative, they will be very successful in their future lives. Currently, students are often presented with ready-made materials, and they are not required to make their designs. Unfortunately, children are accustomed to it, become free-riders, and get lazier. The main needs of children are activities that develop their creativity and imagination. It is both more enjoyable and more useful. I think that if this training is given from the ground up, with emphasis on imagination and creativity, that is, if some things are created from the ground, engineering and design skills will improve."* (Ö4)

*"It is very useful if it is earned. Engineering is already built on design. Unfortunately we do not want to do it, but it is teaching by heart. In my opinion, if we perform a teaching in which students can use their imaginations, useful things can arise. Activities for developing materials should be increased in science class."*(Ö2)

*"It can be transferred. However, first of all, it is necessary to eliminate the problem of lack of tools and materials in schools and to design an integrated program. What I mean by integrated is a program design in which discipline fields can be combined. For example, even a student designing a project in a science lesson can be effective in gaining these skills. Therefore, science lessons are very suitable for these skills."* (Ö9)

### *3.1.4 Realization of an education where science, technology, mathematics, and engineering are found together*

In the fourth question of the interview, the following question was asked to the teachers: "Can an education with science, technology, mathematics and engineering take place? If yes, can you give an example of this?" The categories and codes created according to the answers obtained are given in Table 5 below.

*Table 5:* Teachers' thoughts about teaching, including Science, Technology, Mathematics and Engineering.

| The realization of teaching that includes Science, Technology, Mathematics, and Engineering together | Frequency |
|---|---|
| Realizable | |
| Students make the designs in the activities | 8 |
| Increasing imaginative activities | 7 |
| Active involvement of students | 6 |
| Enabling students to find solutions to the problems they encounter in daily life | 6 |
| Students developing materials in the course | 4 |
| Teachers actively use Technology | 3 |
| Difficult to perform | 2 |
| Insufficient lesson hours | 5 |
| Teachers inadequate in Technology | 4 |
| Teachers tend to prefer easy ways of teaching | 4 |
| Teachers with high age levels have a particularly closed attitude towards innovations. | 3 |
| | 2 |

As shown in Table 5, eight of the teachers stated that teaching involving science, technology, mathematics, and engineering could be carried out. In contrast, five stated that it was difficult to deliver such teaching. Teachers argued that science teaching based on science, technology, mathematics, and engineering would be carried out by the students making the designs in the activities (7 teachers), increasing their imaginative activities (6 teachers), and realizing the teaching by providing active participation (6 teachers). On the other hand, teachers argued that it is difficult to carry out such a science education in our current education system due to the insufficient lesson hours (4 teachers), the inadequacy of teachers regarding technology (4 teachers), and teachers' tendency to prefer easy ways in teaching (3 teachers). Sample quotations from the answers obtained from the fourth question of the interview are given below.

*"It can be realized. I think it can be used in laboratory activities. For example, let's say we install a simple electrical circuit; when we give the student the opportunity to plan and design it, the engineering skills of the student come into play. But the aim here is not to give the student a ready circuit, but it should be the student's design. We often use mathematics when calculating problems. We already use technological tools in the whole process. In addition, while teaching, experiments can be done based on more imagination, the experiments can be left to students, and they can be products that students will reveal with their imagination rather than directly addressing the subject."(S8)*

*"If we think in terms of the curriculum, there will be a shortage of time in realizing such teaching. After all, there are topics to be covered in the curriculum within a 40-minute class hour. The teacher will have problems covering the topics and giving the students the time it takes to do the appropriate activities, or they will keep the time required for the activities in much less time. Students should be able to transfer what they see in science to technology, transfer what they learn in technology to mathematics, and support it in a way that is intertwined with each other." (C5)*

*"It can be realized. A science project can be considered. Students are given a problem and asked to find a solution. For example, they are asked to develop a tool that will make them easier to carry their bags as their bags are too heavy. First, the design phase of this tool includes engineering skills as it is; maybe it will need leverage from science lesson topics to design this tool. In addition, the student will have to perform certain calculations when making this design. Even this requires the four fields to be used together." (O9)*

### *3.1.5 Science subjects that can be taught by interrelating science, technology, engineering, and mathematics*

In the fifth question of the interview, the following question was asked to the teachers: 'If you were going to teach by integrating science, technology, engineering, and mathematics, what science subjects would you apply this method to? Why?" The categories and codes created according to the answers obtained are shown in Table 6 below.

*Table 6:* Teachers' thoughts on the state of teaching, including Science, Technology, Mathematic, and Engineering

| Science subjects that Science, Technology, Engineering, and Mathematics will be applied about each other | Frequency |
|---|---|
| Physics | 8 |
| Simple Electric Circuits | 7 |
| Force and Motion | 6 |
| The pressure of Solid, Liquid, and Gases | 5 |
| Space and Solar System | 4 |
| Light and Sound | 3 |

| | |
|---|---|
| Biology | 5 |
| Living World | 4 |
| Systems in Our Body | 3 |
| The Circulatory System | 2 |
| Excretory System | 1 |
| Support and Motion System | 1 |
| Digestive System | 1 |
| Nervous System | 1 |
| Chemistry | 4 |
| Heat and Temperature | 3 |
| Particulate Structure of Matter | 2 |
| Pure Substances and Mixtures | 1 |
| Acids and Bases | 1 |

As shown in Table 6, eight of the teachers suggested that within the scope of a science lessons, science, technology, mathematics, and engineering could be applied by associating them in the 'Physics'. They stated that within the category of physics subjects, this method could be applied for simple electrical circuits (7 teachers) and force and motion (6 teachers). On the other hand, teachers argued that teaching in subjects of science category could be carried out with an interdisciplinary approach in the subjects of 'biology' category (5 teachers). Finally, teachers stated that with the interdisciplinary approach, science teaching could be applied in subjects within the chemistry category (4 teachers). Sample quotations from the answers obtained from the fifth question of the interview are given below.

*"I think these types of approaches can be used more in physics topics. I can apply it on biology issues after physics issues but, I don't think it can be adapted to chemistry too much because the physical facts are easier to shape and embody than in chemistry at the design stage. For example, it is easier to chart or symbolize an experiment in a physics class. I can apply this approach to simple electric circuits, especially in physics. Because in general, this subject contains all of mathematics, science, and engineering. I can make students take a simple level of measurement that measures the pulse in the circulatory system of biology, or I can ask them to embody it by creating a design that shows systemic circulation."* (Ö6)

*"İt applies to all topics; I do not want to limit myself. Any issue where real-life problems can be addressed requires a problem-solving process. The solution to this problem requires all four field skills. An idea, a solution proposal will surely arise in the solution of the problem. For this to occur, all four field skills are required in most cases."* (Ö7)

### *3.1.6 Advantages of science teaching based on the integration of science, technology, mathematics, and engineering*

In the sixth question of the interview, the following question was asked to the teachers: "Are there advantages of teaching by combining science, technology, mathematics, and engineering with an interdisciplinary approach? If so, explain what kind of advantages can science teaching have in this manner." The data generated according to the answers obtained from the sixth question are shown in Table 7.

*Table 7:* Advantages of Science teaching based on Science, Technology, Mathematics, and Engineering integration

| Advantages of Science teaching based on Science, Technology, Mathematics, and Engineering integration | Frequency |
|---|---|
| Advantages for the student | 10 |
| Interest in Science and Technology lesson | 8 |
| The prefer to learn permanently | 7 |
| Supporting meaningful learning | 7 |
| Increasing academic success | 6 |
| The need for the development of mental, affective, and psychom skills | 5 |
| Increasing student's active participation | 4 |
| Being involved in cooperative learning | 3 |
| Goal setting / awareness | 3 |
| It will improve problem-solving skills | 3 |
| Improving communication skills | 2 |
| Review the development of critical thinking skills | 2 |
| Improving creativity | 2 |
| Improving your imagination | 1 |
| Improving self-confidence | 1 |
| Improving holistic thinking skills | 1 |
| Advantages for the teacher | 4 |
| Making teachers aware of their competencies | 3 |
| Creating opportunities for teachers' professional development | 2 |
| Making her love her job more | 2 |
| Enabling Technology to be intertwined | 1 |
| Advantages for our country | 4 |
| Increasing the quality of education | 3 |
| Training qualified staff | 3 |
| Technological developments increase | 2 |
| To train students more equipped | 2 |
| The development of the country's economy | 2 |
| Development of medical and Engineering fields | 1 |
| More productive student profile to go to university | 1 |

All of the teachers stated that science teaching based on integrating science, technology, mathematics, and engineering would be advantageous. As seen in Table 7, the advantages of teaching based on the integration of science, technology, mathematics, and engineering are gathered under three categories: advantages for students, advantages for teachers, and advantages for our country. In terms of advantages for the students, the majority of teachers stated that it would ensure that students love science and technology lessons (8 teachers), and it would provide permanent and meaningful learning (7 teachers). It has been stated in the category of advantages of teaching based on science, technology, mathematics, and engineering integration that it would enable teachers to realize their competencies (3 teachers), provide teachers an opportunity for their professional development (2 teachers), and make them love their profession more (2 teachers). In the category of advantages for the country, the teachers mentioned that the quality of education would increase with the interdisciplinary science education (3 teachers), qualified staff would be trained (3 teachers), technological developments would increase (2

teachers), students would be educated more comprehensively (2 teachers), and the national economy would develop (2 teachers). Sample quotations from the answers obtained from the sixth question of the interview are given below. *"First, it will have a great contribution to the students on their critical thinking and problem-solving skills. Collaboration of the designs they will make in groups will enable students to learn from each other, i.e., through their peers. Apart from this, parallel to the preceding, individuals who can express themselves and have high communication skills and confidence will be raised. Students' problem-solving skills will improve, and their use in daily life will increase."*(Ö4)

*"I think it will contribute to the students. Thus, I think that when students combine a holistic study with their knowledge intertwined in other fields, they will be more successful in science, as well as other related courses. In this way, I think these areas will complement each other's deficiencies. The information learned through collaborative and peered learning is much more permanent, meaningful and effective. With mutual communication and group work, students contribute to each other's learning by overcoming each other's shortcomings.."* (Ö3)

*"In this way, students both become aware of the problems around them and try to find solutions and start researching. Later, when the student starts researching, he will first investigate the problem around him and perhaps find a problem he has never paid attention to. Thus, he will develop his imagination and creativity while trying to find a suitable solution. Such an application can be beneficial if it is given from kindergarten where students start to develop themselves in every aspect in terms of science, mathematics, and design. In addition, while doing these, they also contribute to other courses and learn more meaningfully than memorizing what they have learned. Perspectives develop against the problems around them, and they try to find solutions. To give an example, when a child who drops litter into the environment develops a solution proposal for this issue, they will be more sensitive about dropping litter into the environment or will try to make the people around him more sensitive with the proposed solution."* (Ö7)

*"This may contribute to students' future career choices because the children at that age can be influenced by choice of the profession even from the movies they watch. If he likes to work with science, mathematics, and technology while developing materials, he can set himself a goal for his future, and this can be very effective in his professional development."* (Ö1)

*'There certainly is. Such an approach also gives the student integrated thinking skills. Thus, he can solve a problem he encounters much more quickly.'* (Ö10)

### *3.1.7 Disadvantages of science teaching based on the integration of science, technology, mathematics, and engineering*

In the seventh question of the interview, the following question was asked to the teachers: "Are there any disadvantages of teaching by combining science, technology, mathematics, and engineering with an interdisciplinary approach? If so, what kind of disadvantages can science teaching have in this way? Explain." The data generated according to the answers obtained from the seventh question are shown in Table 8.

*Table 8:* Difficulties in the implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration

| Problems that may occur in the implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration | Frequency |
|---|---|
| Problems that may occur in practice | 9 |
| The problem of training enough teachers on this subject | 8 |
| Most middle-aged and older teachers may be reluctant | 7 |
| Time is limited | 6 |
| Budget/material deficiencies | 6 |
| Do not require extra responsibility for the teacher | 5 |
| Having difficulties in producing original products | 4 |
| The effectiveness of teachers on the subject affects the student profile | 3 |

The vast majority of teachers stated that, regarding the seventh question, science teaching based on the integration of science, technology, mathematics, and engineering would not have a disadvantage. Still, there may be problems in its implementation (9 teachers). As shown in Table 8, most of the teachers mentioned in practice that there may be a problem of raising sufficient teachers in this regard for the problems that might arise in practice (8 teachers). He also stated that most middle-aged and older teachers would not want to improve in interdisciplinary science teaching (7 teachers). It was mentioned that time may be limited (6 teachers), and budget/material could be inadequate (6 teachers). Sample quotations from the answers obtained from the seventh question of the interview are given below.

*'It would be nice if it is applied, but I think there will be some problems in the application. For example, in most of the schools I have worked, especially teachers over a certain age, are closed to innovations; they do not want to use technology. There are even teachers who still do not know how to use the smartboard. They are also not very prone to learning. I think that new generation teachers like us can deliver such teaching the best, but we may have difficulties in the first place because we have not received any training in this area before.'* (Ö8)

*'If the teacher who delivers this education does not have sufficient knowledge and skills on the subject, then students may be confused. This type of education requires real expertise.'* (Ö7)

### *3.1.8 Whether or not teachers feel sufficient in the implementation of science teaching based on the integration f science, technology, mathematics, and engineering*

In the eighth question of the interview, the following question was asked to the teachers: "Do you feel sufficient in designing the course, giving feedback to the students, and guiding the students in the science teaching process that includes science, technology, mathematics, and engineering? Why?" The data obtained from the eighth question is shown in Table 9.

*Table 9:* Whether teachers feel enough in the implementation of Science teaching based on the integration of Science, Technology, Mathematics, and Engineering

| Whether teachers feel enough in the implementation of Science teaching based on the integration of Science, Technology, Mathematics, and Engineering | Frequency |
|---|---|
| Not feeling enough | 10 |
| Lack of practice in Science, Technology, Mathematics, and Engineering integration | 8 |
| Lack of trust in the use of Technology | 7 |
| Lack of self-confidence in designing | 6 |
| Lack of application due to lack of tools/materials | 5 |
| Feeling enough | 2 |
| Feeling sufficient in the field of Science | 1 |
| Trusting his knowledge in Mathematics | 1 |

As shown in Table 9, most of the teachers stated that they did not feel sufficient in applying STEM, giving feedback, and guiding students (10 teachers). Teachers stated that they did not feel sufficient about STEM due to reasons such as lack of application about he integration of science, technology, mathematics, and engineering (8 teachers), lack of confidence in technology (7 teachers), and lack of self-confidence in designing (6 teachers). On the other hand, two teachers stated that they felt sufficient. One of the teachers stated that he felt sufficient in the application of STEM in science lessons because he felt confident science, and another teacher-trusted his knowledge in the field of mathematics. Sample quotations from the answers obtained from the eighth question of the interview are given below.

*"No, I do not feel sufficient. Today, if they ask me to apply this method, I will have problems as I do not have any previous experience, and I have not performed any application in this area or received any training whatsoever. For this reason, I will experience problems in implementation."* (Ö1)

*'No, I do not feel sufficient because I have not received any relevant training or conducted any relevant practice.'* (Ö2)

*'I do not feel adequate because the environment and the equipment of the institution I work for are not suitable for me to carry out this training. However, even though it is very rare, I perform such applications, and I have serious difficulties only during the applications. The lack of media and equipment challenges me seriously. I also have not received any training on how to deliver such education.'* (Ö9)

### *3.1.9 Recommendations of pre-service teachers for science teaching based on the integration of science, technology, mathematics, and engineering to be applied by their teachers upon graduation*

In the ninth question of the interview, the following question was asked to the teachers: "Do you have any recommendations for science teaching based on the integration of science, technology, mathematics, and engineering to be applied by teachers when they graduate? If so, what are these recommendations?" The data obtained from the ninth question is shown in Table 10.

*Table 10:* Teachers' suggestions for the implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration

| Recommendations for the implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration | Frequency |
|---|---|
| Suggestions | |
| Taking courses about the application of STEM in the Science course during their undergraduate education | 9 |
| Making applications about STEM during the undergraduate education | 9 |
| Using Technology more during undergraduate education | 8 |
| Participating in the training organized by the MEB taking an active role | 7 |
| Preparation of a graduation project about STEM | 7 |
| Organizing STEM project competitions attended by faculties of education. | 6 |
| | 5 |

As shown in Table 10, nine of the teachers suggested that courses should be received for the implementation of STEM during their undergraduate studies. While eight teachers suggested to practice STEM-related education during their undergraduate education, seven teachers suggested that they should use technology more during their undergraduate education and should participate in the training activities organized by the Ministry of Education and take an active role. Sample excerpts from the answers obtained for the ninth question of the interview are given below.

*'I can propose to acquire theoretical and practical knowledge about this subject during the undergraduate education in education faculties. Because I believe that, if the necessary theoretical information is obtained on this subject and necessary practical applications are performed before starting the profession, students will be more successful.'* (Ö10)

*'My suggestion is to give a comprehensive education on this subject to the teachers..'* (Ö3)

*3.1.10 Duties of teachers, Ministry of National Education and parents for the successful implementation of science teaching based on the integration of science, technology, mathematics, and engineering.*

In the tenth question of the interview, the following question was asked to the teachers: "Explain what can be done for the successful implementation of science teaching based on the integration of science, technology, mathematics, and engineering." The data obtained from the tenth question is shown in Table 11.

*Table 11:* Duties of teachers, MEB and parents for the successful implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration

| Duties of teachers, MEB and parents for the successful implementation of Science teaching based on Science, Technology, Mathematics, and Engineering integration | Frequency |
|---|---|
| Duties to MEB | 8 |
| In-service training/seminars should be organized | 7 |
| Science textbooks with exemplary activities related to STEM should be organized | 5 |
| Heterogeneous distribution of specialist teachers to primary schools | 2 |
| Tasks for teachers | 7 |
| Participating in the in-service training organized by the MEB | 6 |
| Using more technological tools in the lesson | 5 |
| Helping with teachers in different branches | 4 |
| To closely follow the technological developments | 4 |
| To follow the developments in Engineering | 4 |
| Arranging a lesson plan on subjects where interdisciplinary Science education can be applied | 3 |
| Guiding students on the subject | 2 |
| Duties to parents | 2 |
| Not interfering with the designs of their children | 2 |

As it can be seen in Table 11, there are three categories, namely MEB (8 teachers), teachers (7 teachers) and parents (2 teachers) for successful implementation of teaching (STEM) based on the integration of science, technology, mathematics, and engineering. Seven of the teachers stated that MEB should organize in-service training/seminars, and 5 of the teachers stated that starting from primary education, science textbooks with sample activities related to STEM should be organized at every grade level. In addition, 6 of the teachers stated that science teachers working actively should participate in the in-service training organized by MEB. Five of the teachers mentioned that technological tools should be used more widely in the classes. Finally, two teachers talked about the duties of parents to successfully implement their teaching based on the integration of science, technology, mathematics, and engineering. Two of the teachers stated that parents should not interfere with the designs of their children. Sample quotations from the answers obtained from the tenth question of the interview are given below.

*'First of all, in-service training should be provided to the teachers by the ministry, in which teachers are also active. The teacher should follow the developments that are intertwined with our current life, not only in his field but also in different fields such as technology and engineering, and transfer what he learned to the students by giving examples. Teachers should always be open to innovation and should not hesitate to seek help.'* (Ö1)

*'Teachers should always follow the innovations and improve themselves very well in this regard. They can research this subject on the internet. They can participate in in-service training organized by the Ministry and exchange ideas with their teacher colleagues.'* (Ö2)

*'First of all, teachers who are the practitioners of this training should be trained on the subject. Adequate equipment support should be provided to public schools. I think that if these are done, every teacher will want to deliver such training.'* (Ö6).

## IV. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

Almost all teachers talked about the existence of the relationship between science, technology and mathematics, which is the first question of the interviews conducted with the aim of determining the opinions of the teachers who teach science education in a private school in the TRNC about the integration of science, technology, mathematics, and engineering (STEM). These findings are consistent with other studies (Sungur and Marulcu, 2014; Kızılay, 2016).

When teachers' views on engineering were examined, it was found that all participants (10 teachers) associated engineering with design. At the same time, it was determined that they thought that engineering skills improved psychomotor skills (8 teachers) and helped to produce products and make inventions (7 teachers). The results obtained in this direction are similar to the results of other studies in the literature (Marulcu and Sungur, 2012; Sungur and Marulcu, 2014; Kızılay, 2016; Özçakır and Çalışıcı, 2016; Yıldırım, 2017; Yıldırım and Türk, 2018).

When the opinions of the teachers about whether or not the engineering skills can be gained in science teaching process, the majority of the teachers (9 teachers) expressed their opinion that they can be gained, it has been suggested that engineering skills can be gained by students by conducting activities related to experimental and material design in class (8 teachers), teaching by doing and living (7 teachers), and teaching science (5 teachers) where the creativity of the students is at the forefront. Similar results were found by Marulcu and Sungur (2012), Yıldırım (2017) and Yıldırım and Türk (2018). On the other hand, two teachers stated that these skills could not be gained due to reasons such as the difficulty of access to materials required for this education and the implementation of this method in schools with low economic level, and one teacher each mentioned the subject-centered education in our education system and teachers' inadequacies in this regard.

When the opinions of teachers on teaching a combination of science, technology, mathematics, and engineering were examined, 8 of the teachers stated that teaching involving science, technology, mathematics, and engineering could be carried out and gave examples of how this could be applied in science courses. While giving examples, it was determined by the researcher that teachers had difficulties in including technology and engineering in the process. On the other hand, five teachers stated that interdisciplinary science education could not be carried out in every school in our country due to reasons such as class hours for teachers (4 teachers), the inadequacy of teachers in terms of technology (4 teachers), and the tendency of teachers to prefer short-cuts in teaching (3 teachers). In the literature, Hacıoğlu et al. (2016) found similar results to those obtained in this study.

Among the courses which could be delivered using an integrated approach between science, technology, engineering, and mathematics, physics (8 teachers), biology (5 teachers), and chemistry (4 teachers) were mentioned. In physics, teachers stated that they can be applied mostly on simple electrical circuits and force and motion, on the world of living things in biology, and on heat and temperature in chemistry. In the research, it was determined that teachers had difficulty in giving interdisciplinary teaching on chemistry subjects in science courses. In this context, it could be suggested to undertake studies with more exemplary activities in chemistry within the science course in the literature. In the study conducted by Eroğlu and Bektaş (2016), it was found that this approach can be applied mostly in physics subjects. Then it can be applied in chemistry and biology, respectively. At the end of the research carried out in this study, the finding that interdisciplinary science teaching can be applied in biology subjects after physics topics attracts attention.

In addition, all teachers provided their opinions that interdisciplinary science teaching would be advantageous. In terms of student benefits, they stated that they would make students love science and technology lessons (8 teachers), provide permanent and meaningful learning (7 teachers),

and increase academic success (6 teachers). Similar results are included in the literature (Marulcu and Sungur, 2012; Bozkurt Altan et al., 2016; Çınar, Pirasa and Sadoğlu, 2016; Eroğlu and Bektaş, 2016; Hacıoğlu et al., 2016; Kızılay, 2016; Özçakır and Çalışıcı, 2016; Yıldırım, 2017; Yıldırım and Türk, 2018).

In terms of the advantages of interdisciplinary science teaching as regards teachers, the teachers stated that they would make science teachers realize their competencies (3 teachers), create opportunities for professional development of teachers (2 teachers), and make them love their profession more (2 teachers). Similar results were seen in the literature (Çınar, Pirasa and Sadoglu, 2016; Eroğlu and Bektaş, 2016; Hacıoğlu et al., 2016; Özçakır and Çalışıcı, 2016; Yıldırım, 2017; Yıldırım and Türk, 2018). In terms of the advantages of interdisciplinary science education for our country, teachers mentioned the increase in the quality of education (3 teachers), the training of qualified staff (3 teachers), the increase in technological developments (2 teachers), the provision of better education to students (2 teachers) and the development of the national economy (2 teachers). In studies conducted by Çorlu, Caproro and Çorlu (2015) and Yıldırım (2017), it was argued that interdisciplinary education should be used as an alternative in teacher education. This result is consistent with the data obtained from this study.

Regarding the implementation of interdisciplinary science education, nine of the teachers stated that there might be problems in implementating science education in our country. They mentioned that there may be a problem of training enough teachers (8 teachers), and that most middle-aged and older teachers may be reluctant (7 teachers), that the time is limited (6 teachers), and that budget/materials are inadequate (6 teachers); therefore they expressed that there might be problems in practice. Similar results were found in the literature (Bozkurt Altan et al., 2016; Eroğlu and Bektaş, 2016; Hacıoğlu et al., 2016; Özçakır and Çalışıcı, 2016; Yıldırım, 2017).

All of the teachers (10 teachers) stated that they did not feel sufficient in the implementation of interdisciplinary science teaching. In parallel with this situation, the following determinations were made regarding the ability of teachers to successfully apply interdisciplinary science teaching when they graduate: Nine of the teachers take lessons for the implementation of STEM during their undergraduate education, eight of them apply for STEM during their undergraduate education, and all seven teachers suggested using technology more during their undergraduate studies and taking an active role by participating in the training organized by the ministry. The findings obtained are similar to the ones provided in the literature (Marulcu and Sungur, 2012; Sungur and Marulcu, 2014; Hacıoğlu et al., 2016; Yıldırım, 2017). As stated by Çorlu (2014) and Yıldırım (2017), it is considered that their education in this context is important for educators to graduate with competence from STEM education.

For interdisciplinary science teaching to be applied successfully in our country, the teachers stated that the responsibility falls to the Ministry of National Education followed by teachers and parents. Organizing in-service training/seminars (7 teachers) and organizing science textbooks with sample activities related to STEM (5 teachers) are among the duties of the Ministry of National Education. The findings obtained are similar to the literature (Sungur and Marulcu, 2014; Eroğlu and Bektaş, 2016; Hacıoğlu et al., 2016; MEB-YEĞİTEK, 2016; Yıldırım, 2017). Among the duties assigned to teachers is participation in in-service training organized by the Ministry of National Education (6 teachers) and better use of technological tools in the course (5 teachers). Trying to avoid interfering with the designs of their children (2 teachers) was shown among the duties of the parents in this regard. The findings obtained are similar to the ones found in the studies conducted by Çınar, Pirasa, and Sadoglu (2016) and Yıldırım (2017).

According to the results of the research, it was understood that the teachers who deliver science education did not have difficulty in associating science and mathematics with each other in the integrated science teaching process, which includes science, technology, mathematics, and

engineering. However, it turned out that they had difficulty integrating technology and engineering into the process and designing this education inappropriate science topics. On the other hand, teachers talked about the advantages of interdisciplinary science teaching but stated that there would be problems in implementating all teachers in our country. To successfully implement integrated science teaching in our country upon graduation, they suggested that they take applied courses that would provide teachers with knowledge and experience in this subject during their undergraduate studies. As a result, it was determined that teachers generally have a positive perception about teaching science based on science, technology, mathematics, and engineering, but that they felt the need to have knowledge and experience in this area as well as students in terms of designing and applying science and technology teaching by the interdisciplinary approach.

In line with the data obtained from the research, the following suggestions can be presented.

- Educators working at all levels from pre-school to higher education should be included in the activities for STEM education.
- In future studies, the STEM-related opinions of not only teachers working in the field of STEM but also teachers and pre-service teachers in social branches other than STEM can be examined.
- As a result of the collaboration between YÖK (Higher Education Institution) and MEB, a course on the integration of science, technology, mathematics, and engineering can be offered for students studying in teaching at universities.
- To create a reliable source of information and guide teachers on this issue, sample activities deemed appropriate by the MEB for the implementation of STEM in the teaching process can be posted on the website, and these activities can be made available to pre-service teachers.
- Low-cost STEM activities can be included in the science and technology textbooks.
- Appropriate STEM activities can be organized for education faculties to work in cooperation with engineering faculties and to apply technology and engineering in primary / secondary schools.
- Applied in-service training, where teachers are active, can be provided by MEB to ensure that the teachers on duty are informed about STEM and can conduct implementation.

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# About the Possibility of Surface and Volume Creation from the Equivalence Principle

*Spiros Koutandos*

## ABSTRACT

We assume from previous work that the mass of the electron creates a spacetime curvature thus giving a picture of local change of volume and surface. The assumption comes from the relativistic radius of the electron which gives as a first estimate for a spacetime curvature. The volume created seems to be depending on the dielectric susceptibility which alters the speed of light thus creating a new metric. We find a formula for this new volume and the rate of change of the surfaces locally.

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## ABSTRACT

*We assume from previous work that the mass of the electron creates a spacetime curvature thus giving a picture of local change of volume and surface. The assumption comes from the relativistic radius of the electron which gives as a first estimate for a spacetime curvature. The volume created seems to be depending on the dielectric susceptibility which alters the speed of light thus creating a new metric. We find a formula for this new volume and the rate of change of the surfaces locally.*


## I. INTRODUCTION

If we generalize the surface to area equivalence for a black hole [1] as a valid law describing the quantum phenomena taking in mind that the logarithm of probability is proportional to the entropy we naturally arrive at the following relationship:

$$dP = \frac{d|\psi|^2}{N} = 2\frac{|\psi|^2}{N^2 K}dS \tag{1}$$

In equation (1) K stands for the spacetime curvature found in our paper [2] which if multiplied by the dielectric susceptibility gives:

$$K\chi(\vec{r}) = \frac{dS}{dV} \tag{2}$$

The right part of equation (2) is the surface to volume ratio.

We put forth some of the formulas we had derived in the afore mentioned article [2]:

$$\frac{\hbar^2}{2mN}\Delta|\psi|^2 = B = V\frac{dP}{dV} = \frac{|\psi|^2}{\chi}\frac{mc^2}{N} \tag{3}$$

$$P = Pressure = \frac{|\psi|^2}{N}(E - U) \tag{4}$$

Combining formulas (4) ,(3),(2),(1) we get:

$$B = V\frac{dP}{dV} = 2\frac{|\psi|^2}{N^2}V\chi(E - U) = mc^2\frac{|\psi|^2}{N\chi} \tag{5}$$

The solution of equation (5) is equation (6):

$$2\chi^2 = \frac{mc^2}{(E-U)}\frac{N}{V} \tag{6}$$

A natural consequence of equation (1) is the following result:

$$\nabla|\psi| = 2|\psi|\frac{\nabla S}{NK} \tag{7}$$

Therefore by using equation (7) together with the results of the references[3,4] the velocity of the particle is written as:

$$\vec{v} = \psi\frac{d\vec{r}}{dt} + 2i\psi\frac{\nabla S}{NK} \tag{8}$$

$$\frac{d\vec{r}}{dt} = \frac{\hbar}{m}\nabla\phi + \frac{e}{mc}\vec{A} \tag{9}$$

Next we are going to produce the formula for vorticity by following reference [5]:

$$\vec{\Omega} = \frac{\nabla S}{NK} \times \frac{d\vec{r}}{dt} \tag{10}$$

The meaning of equation (10) is that vorticity is a vector showing towards the change of volume.

However the change of volume and surface is phenomenological only due to the presence of mass from the equivalence principle which creates a curvature in spacetime. Thus we shall have the following restriction:

$$\frac{dS}{dt} = 0 = \nabla S\cdot\frac{d\vec{r}}{dt} + \frac{\partial S}{\partial t} \tag{11}$$

From equations (11) ,(9) and (7) and by using the law for the continuation of current we derive the following result:

$$\frac{\partial|\psi|^2}{\partial t} = \frac{1}{KN}|\psi|^2\frac{\partial S}{\partial t} \tag{12}$$

Therefore during the passage from on quantum state to the other the surfaces change locally.

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## II. CONCLUSIONS

Since we are aware of the well known formula from thermodynamics connecting volume change to entropy we shall use it this time to find the final formula and solve for the volume:

$$\frac{dS}{NK} = \frac{dV}{V} \rightarrow \chi = \frac{N}{V} \tag{13}$$

Using equations (13) and (6) apart from a factor of two which we are unsure about we find:

$$E - U = mc^2 \frac{V}{N} \tag{14}$$

The formula for pressure now is written as follows:

$$P = mc^2 |\psi|^2 \frac{V}{N} \tag{15}$$

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# Economic Valuation of Treated Wastewater use in Sustainable Agriculture - New El-Mahsama Wastewater Treatment Plant in Sinai, Egypt

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## ABSTRACT

In 2020, El-Mahsama wastewater treatment plant (WWTP) was constructed in Sinai, Egypt to treat 1.0 million $m^3$daily of agricultural drainage water. This research aims to identify the economic valuation of the favorable safe and sustainable WWT management in agriculture. The highest cost was construction of agriculture schemes including the installation of the modern irrigation systems, land management services, pumps, pipes, nozzles, valves, civil and other auxiliary works. Benefits accrued from agriculture schemes was on the top benefit. In three years, the project recovers its full costs, then it starts to accrue benefits. The cost-benefit ratio was doubled in 10 year of operation. It was proven that expansion in constructing WWTPs and use of the treated wastewater safely and sustainably for irrigating agriculture schemes as well as wood trees is a successful practice in the future. This justifies the potentiality of investments in wastewater treatment domain.

*Keywords:* cost-benefit analysis (CBA), economic valuation, use of treated wastewater, sustainable agriculture management, Sinai development, El-Mahsama wastewater treatment plant.

*Classification:* For Code: 090409

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*In 2020, El-Mahsama wastewater treatment plant (WWTP) was constructed in Sinai, Egypt to treat 1.0 million m³daily of agricultural drainage water. This research aims to identify the economic valuation of the favorable safe and sustainable WWT management in agriculture. The highest cost was construction of agriculture schemes including the installation of the modern irrigation systems, land management services, pumps, pipes, nozzles, valves, civil and other auxiliary works. Benefits accrued from agriculture schemes was on the top benefit. In three years, the project recovers its full costs, then it starts to accrue benefits. The cost-benefit ratio was doubled in 10 year of operation. It was proven that expansion in constructing WWTPs and use of the treated wastewater safely and sustainably for irrigating agriculture schemes as well as wood trees is a successful practice in the future. This justifies the potentiality of investments in wastewater treatment domain.*

*Kyewords:* cost-benefit analysis (CBA), economic valuation, use of treated wastewater, sustainable agriculture management, Sinai development, El-Mahsama wastewater treatment plant.

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## I. INTRODUCTION

Mismanagement of wastewater irrigation would create health, economic and environmental impacts (Mohammad and Ayadi, 2005). Among the consequences, unfavourable effects on crops productivity and soil pollution (Vazquez-Montiel *et al.,* 1996). The available fresh water resources in Egypt from the River Nile, few coastal precipitations and small non-renewable deep groundwater collectively are significantly less than the quantity needed to produce the adequate food demand of the increasing population of Egypt. The deficit is about 54 billion m³ per year (MWRI, 2018). In Egypt, multiple reuse of agricultural drainage water is widely practiced. It contributes to filling the gap between the available freshwater resources and water demands for all sectors. Reusing the agricultural drainage water several times fills about 20 billion m³ per year of that deficit gap. Importing virtual water (key commodities are wheat, meat and oils) closes the remaining deficit of about 34 billion m³ per year (NWRP, 2018). According to the National Water Resources Strategy of Egypt till year 2030, safe utilization of treated wastewater should be expanded in irrigating newly reclaimed agricultural schemes. In addition, Khairy *et al.*, (2020) stated that the wastewater treatment of the agricultural drains leads to less carbon emission to the atmosphere.

The National Water Resources Strategy of Egypt focuses more on the effective sustainable development of the Sinai Peninsula (MWRI, 2018). One of the agriculture development projects in middle Sinai is designed to depend mainly on the treated wastewater from El-Mahsama wastewater treatment plant (WWTP) that could add about 265 million m³/year for irrigating large agricultural schemes (Allam, 2020). The Egyptian Wastewater Treatment Code (ECP 501) issued on 2015, permits the use of

treated wastewater in irrigating crops such as cotton, maize, wheat, oil crops, fiber crops, and animal fodder taking into consideration the required health safety measures stated by the World Health Organization, (MHUUC, 2015). That Egyptian Code is flexible yet the health safeguards of the humans and environment are strictly maintained. The ECP 501 classifies treated wastewater into four grades (A, B, C, and D) depending on the level of treatment, and prohibits the use of treated wastewater for any edible vegetable crops without cooking such as cucumber or tomatoes.

Khairy and Abdel Ghany in 2021 proved that the "favorable safe and sustainable agricultural management" for using El-Mahsama WWTP water using modern drip and sprinkler irrigation systems could be a 1st scheme (about 30,000 ha) cultivated with wheat, barley, beans, and maize, and then a 2nd scheme (about 22,300 ha) cultivated with cotton, flax, kenaf, oil crops as jojoba, jatropha, canola and sunflower. In addition, the Egyptian environmental laws strictly forbid the disposal of any low quality waters into Suez Canal, being an international navigational route. The disposal of agricultural drainage water from those schemes is planned to be diverted to irrigate wooden trees forest "mahogany" for high-quality wood production. The risk of shortage of water in El-Mahsama Drain (or temporary stopping El-Mahsama WWTP) shall be compensated by developing a number of groundwater wells (with reasonable quality) to be readily standby for irrigating the agricultural schemes in such unlikely water shortage situations. The sludge waste of El-Mahsama WWTP could be used after anaerobic digestive processes to produce compost used as animal fodder and could further be processed to produce biofuel. That biofuel could be considered a source of energy for the nearby isolated communities' daily life activities. The remaining harmful effluent sludge waste from El-Mahsama WWTP should be disposed into secured and impervious evaporation ponds or depressions. The dried accumulated harmful sludge in those evaporation ponds should be removed periodically and cautiously, then carried in closed trucks to remote safe dumping sites/depressions in the deserts according to the safeguards procedure stated in the international dumping manuals of hazardous materials (Mercer *et al.,* 2004; Environment Agency, 2004; Nawrocki, 1976).

The climate change risks on crop productivity should be minimal due to crop high resilience to climate change. Furthermore, less carbon emission should occur due to removal of pollutants during water treatment. All types of human health risks and environmental quality risks are not expected when the "favorable alternative sustainable manage- ment" is applied. Safeguards associated with treated wastewater handling, management, and use shall be strictly met. The socio-economic benefits associated with the application of that favorable sustainable agricultural management is high (Khairy and Abdel Ghany, 2021).

There are numerous socio-economic costs associated with the deterioration of water quality, including costs related to water treatment and health care, impacts on economic activities such as agriculture, fisheries, industrial manufacturing and tourism, degradation of ecosystem services, reduced property values, and opportunity costs of further development. Further economic, social, and environmental benefits can arise if WWT management practiced wisely (WWAP, 2012). Comparison between the estimated cost of no action (benefits lost) with the cost of action versus the significant benefits is also possible to provide essential information for decision-making processes (Molinos-Senante *et al.*, 2013; Bateman *et al.*, 2006).

The research problem is the inadequacy of socio-economic evaluation studies and cost-benefit analysis of large wastewater treatment projects including the use of such treated water sustainably in irrigating agriculture crops and wood trees. Wastewater treatment could be a safe and sustainable non-conventional water resource is a key solution that must be tapped in countries located in arid or semi-arid climatic zones and countries with severe water scarcity like Egypt.

## II. RESEARCH OBJECTIVES

Objectives of this research paper are as follows:

1. To develop a simple cost-benefit analysis model (in spreadsheet Microsoft Excel) for using treated wastewater in agriculture with no risks to human health nor environmental quality.
2. To conduct economic valuation analysis for ten years, as a planning guide to avail proper informative development decisions to support the water policy makers in Egypt.
3. To draw reasonable and reliable conclusion and recommendations leading to successful replication in other treated wastewater sites with similar conditions.

## III. MATERIALS AND METHODS

### *3.1 Case study: agricultural schemes irrigated through El-Mahsama wastewater treatment plant*

Year 2020 witnessed the completion of the first drainage wastewater treatment plant in Egypt (El-Mahsama WWTP) for safe use of treated wastewater in irrigating new agricultural schemes (Grade "A" treatment according to the Egyptian code, ECP 501). That project is one of the promising non-conventional solutions to overcome water scarcity challenge Egypt. Figure (1) shows the location of El-Mahsama WWTP and the study area (agricultural schemes). El-Mahsama WWTP is a mega drainage wastewater treatment facility in Sinai Peninsula east of Suez Canal (total area of 42,000 $m^2$, infrastructure cost is 100 million US dollars). It aims to treat the whole El-Mahsama Drain waters rather than letting it run in raw-condition into Lake El-Timsah causing significant negative environmental impacts in the lake's ecosystem (Abd El Samie *et al.*, 2008). El-Mahsama WWTP is currently in experimental and testing phase up to end of 2021. It is planned to treat a blend of domestic wastewater and agricultural drainage water from El-Mahsama Drain and other small nearly agricultural drains. It has a capacity of 1.0 million $m^3$ of treated water per day sufficient to irrigate several agricultural schemes in Sinai. The 1st scheme (70,000 feddans eq. to 30,000 ha) to be cultivated with wheat, barley, beans, and maize, and then a 2nd scheme (about 52,000 feddans eq. to 22,300 ha) to be cultivated with cotton, flax, kenaf, oil crops as jojoba, jatropha, canola and sunflower (Khairy and Abdel Ghany, 2021).

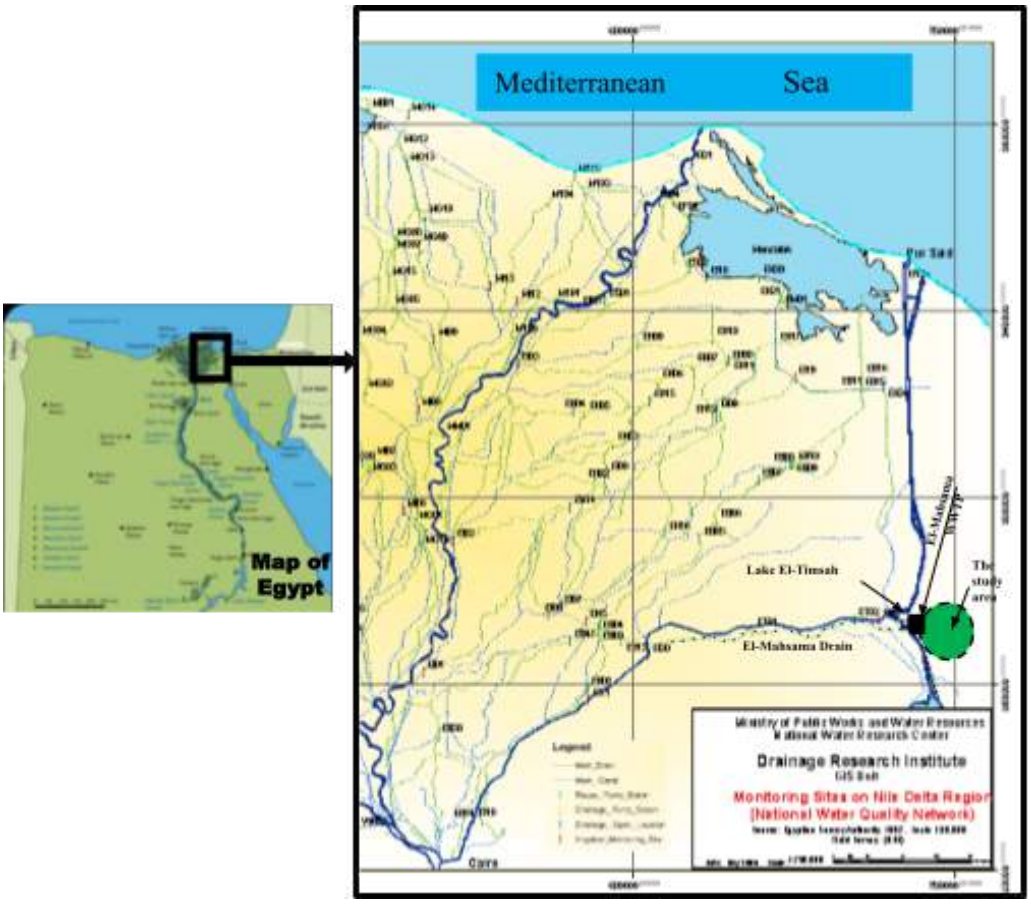


*Figure (1):* Location of New El-Mahsama wastewater treatment plant and the agriculture schemes (the study area) in Sinai *(source: DRI database, 2021)*

## IV. METHODOLOGY

The approach used in this research paper is developing and applying a simple cost-benefit analysis (CBA) model (using spreadsheet in Microsoft Excel) that capable of simulating the annual operation, management, and production of agricultural crops for ten years using the treated wastewater of El-Mahsama WWTP. The favorable safe management should have sufficient precautions to maintain the good environmental quality and to create economic value to the society. Figure (2) articulates the conceptual model used (Anthony E. Boardman *et al.*, 2018). The annual benefits (B) and costs (C) estimated on the vertical axis while time in years (representing the level of construction, operation, management with safeguard precautions applied, and production) is on the horizontal axis. The slope of curve (B) indicates that the increase in safe management and production is an increasing function. The slope of curve (C) indicates that the cost of operation, management and precautions measures are initially increasing but turns to be a function with decreasing rate. The economic efficiency is achieved at certain year of operation where the difference between curve (B) and curve (C) is zero (at point E). The net gain starts to accrue after point E and continues to increase according to the level of management and safe crop production. The breakpoint E should be exceeded in a smallest number of years so as to achieve a real benefit of such WWTP.

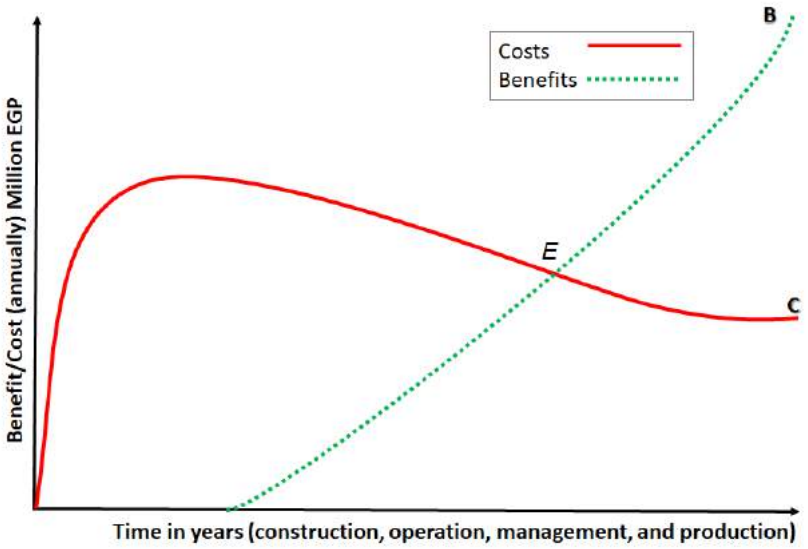


*Figure (2):* Conceptual CBA model used for safe and sustainable management of the treated wastewater of El-Mahsama WWTP in irrigating agricultural crops

CBA compares the costs of the project with its benefits, to determine if the project is economically viable and worthwhile. The span of this research is 10 years starting from the year of operation of El-Mahsama WWTP. A simple CBA includes in the cost side of the analysis both capital expenditures (CAPEX; i.e. the upfront costs of constructing the infrastructure) and operational expenditures (OPEX; the ongoing operational and maintenance costs of the project). For instance, the CAPEX of a water treatment plant includes costs of designing and constructing the plant itself. It also includes construction of the agricultural scheme/s with its irrigation infrastructure. The OPEX includes costs of paying salaries and materials to operate and maintain both the plant as well as the agricultural scheme/s over its expected lifetime. Other costs that are conceptually accounted-for include social costs, such as impacts on human health, and environmental costs like land conservation/degradation, non-renewable groundwater depletion, or contamination prevention works. Techniques for estimating those costs are similar to those for estimating social and environmental benefits, depending on logic and reasonable assumptions (Go, 1988).

With El-Mahsama WWTP operation, various economic, social and environmental benefits will accrue. For instance, it will create profits by selling the agricultural crops, reducing the costs of obtaining irrigation water from remote sources (economic), and creating jobs. In addition, it will reduce illnesses such as diarrheal diseases leading to general health benefits (social) and improve water quality through minimizing contamination in water (environmental). A critical factor for determining economic benefits of such project is comparing it to what would happen if the project was not undertaken (Markandya, 2016; UNWWDR, 2021). Aggregating those benefits to estimate its monetary values can be difficult, as those benefits are with various nature (Molinos-Senante *et al.*, 2013; Bateman *et al.*, 2006).

Net Present Value (NPV) approach is considered in this research. The typical equation used is $NPV = \sum_{t=1}^{T} \frac{NPt}{(1+r)t}$, where NPV is the cumulative net present monetary value, $NP_t$ is incremental present monetary value of (all benefits – all costs) in each year, t ranges from zero to 10 years, r is the discount rate used, and T is the project lifespan which is considered 10 years. NPV is the result of

calculations used to find today's value of a future values (costs and benefits). It accounts for the time value of money and can be used to compare similar economic conditions for various future years. The NPV relies on a discount rate that may be derived from the cost of the infrastructure, operation as well as from the benefits accrue from the agriculture schemes. The discount rate considered in this research was 8.75% p.a. (per annum), (CBE, 2020).

### 3.2 Assumptions and data sets used

Since El-Mahsama WWTP is under experimental and testing operation phase. Also the associated agriculture schemes are not fully operational. The actual detailed data sets required to conduct an economic research and analysis were not available. The monitoring of systems performance is not even operational yet to relay on concerning data acquisition (Karczmarczyk *et al.*, 2021). Therefore, field visits, questionnaires, previous experience, and related literature studies were ruled out because of the difficulty in resolving breaking down costs and benefits in the details required (Logan *et al.*, 1962).

#### 3.2.1 Costs considerations

Some logic and reasonable assumptions and considerations were adopted and used for monetizing the costs and benefits, as follows:

- Infrastructure costs (CAPEX) of El-Mahsama WWTP include cost of all civil, electrical, mechanical and electronic works in El-Mahsama WWTP, but not the land cost. The Government of Egypt availed the land (total area of 42,000 $m^2$) for free because El-Mahsama WWTP is a public good facility run by governmental institutions.
- Irrigation water is free (no volumetric water charges applied for irrigation).
- Annual operation costs (OPEX) of El-Mahsama WWTP (Grade "A" treatment facility according to the Egyptian code, ECP 501) includes cost of fuel, utilities, site utilities, chemical materials, sludge extraction, administration fees, salaries and membranes/consumable/disposable materials. Figure (3) shows typical breakdown of OPEX ratio among the above components.
- Annual maintenance costs of the WWTP (additional part to OPEX) includes cost of spare parts for machines and vehicles as well as fees for technical services providers.
- Infrastructure costs of agriculture schemes (additional part to CAPEX) covering construction cost of modern irrigation systems and land management includes cost of infrastructure of the modern irrigation systems, pumps, pipes, nozzles and valves.
- Annual operation costs of agriculture schemes (additional part to OPEX) include cost of machinery fuel, workers' salaries, farming utilities, seeds, materials (fertilizers and environmentally- degradable pesticides) and other crops services and handling.
- The actual cultivated area is only 0.9 of the total agriculture schemes, the rest left for roads, handling and services facilitation.
- Other costs considered in the CBA were cost due to risk of shortage of water in El-Mahsama Drain, cost due to risk of stopping El-Mahsama WWTP, cost due to risk of disposal of remaining harmful sludge waste of the WWTP, and cost due to risk of climate change.

#### 3.3.2 Benefits considerations

- The seasonal crop production of the 1st agricultural scheme (area of 70,000 feddans) with crops: wheat, barley, beans and maize.
- The seasonal crop production of the 2nd agricultural scheme (area of 52,000 feddans) with crops: cotton, flax, kenaf and oil crops (peanuts, sesame, soya beans, jojoba, canola and sunflower).
- Human health improvements (in three Governorates: Port Said, Ismailia and Suez).
- Environmental quality of Lake Timsah and other sparse benefiting surrounding ponds.
- Socio-economic benefits such as jobs creation and improved livelihood.
- Products-chain beneficiaries including agro-industrial crops processing and marketing, animal meat manufacturing, dairy productions, and trade.

- Disposal of agricultural drainage water from the agricultural schemes in irrigating Mahogany Trees forests (good cash for local markets and export).

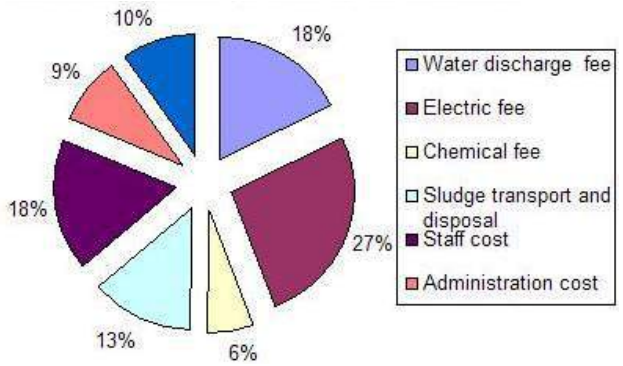


*Figure (3):* Typical breakdown of operation/running (OPEX) costs of a wastewater treatment plant - source: *(COST Water, 2021)*

There are clusters of assumptions and hypothesis adopted and used in this research paper, those were cited from authenticated and relevant references that suit the Egyptian conditions, as shown in Table (1). Costs estimation were based on the net present value (NPV). Quantification of environmental and social impacts and benefits in the study area were based on approaches and methodologies adopted by the World Health Organization and the World Bank (WB, 2002).

*Table (1):* Costs and benefits data, assumptions, and justifications of the used CBA model for El-Mahsama WWTP operation and use *(sources are authenticated references, otherwise values are assumed by the authors)*

| Elements/sub-elements of CBA | Assumptions/justifications/ references/sources | |
|---|---|---|
| *Costs* | | |
| Land tenure: Government of Egypt availed the land of El-Mahsama WWTP for free | El-Mahsama WWTP is a public good facility owned & operated by the Ministry of Housing, Utilities and Urban Communities similar to all Egyptian WWTPs *(MHUUC - Wikipedia, 2021)* | |
| Infra-structure costs in El-Mahsama WWTP (CAPEX) include all civil, electrical, mechanical, and electronic works as well as transportation tools. | 1.0 million USD | *(Allam, 2020; Rewater, 2019)* |
| Type and area of El-Mahsama WWTP (Grade "A" treatment facility)_ | Total area is 42,000 $m^2$ | *Masr Consultants, 2019* |
| Operation costs (OPEX) of WWTP:<br>- *Cost of electricity, gas and fuel*<br>- *Utilities and materials*<br>- *Administration fees and salaries (100 technicians+12 managers+500 workers)*<br>- *Consumable/disposable materials* | *200,000 EGP per month*<br>*100,000 EGP per month*<br>*1,580,000 EGP per month*<br>*1,500,000 EGP per month* | for all machineries *(COS T Water, 2021; (Molinos-Senante et al., 2013)* |

| | | |
|---|---|---|
| Maintenance costs (OPEX) of WWTP:<br>- *Cost of spare parts for machines*<br>- *Cost of spare parts for vehicles and trucks*<br>- *Fees for technical services providers* | *100,000 EGP per month*<br>*50,000 EGP per month*<br>*25,000 EGP per month* | *(Puja Mondal, 2021; Molinos-Senante et al., 2013)* |
| Infrastructure costs (CAPEX) of agriculture schemes: modern irrigation systems and land management service includes cost of infrastructure: pumps, pipes, nozzles, valves, and the auxiliary works (0.9 of area only, the rest are for services) | *50,000 EGP/feddan* | *(Rawlins et al., 2020)* |
| Operation costs (OPEX) of agriculture schemes: fuel, workers' salaries, utilities, seeds, materials (fertilizers and environmentally-degradable pesticides), periodical maintenance and handling (0.9 of area only, the rest are for services) | *9,000 EGP/feddan/year* | Crop season using modern irrigation system costs between (8,000-12,000 EGP/feddan/year) without fees for irrigation water (free) |
| Cost due to risk of shortage of water in El-Mahsama Drain | *215,063,908 EGP* | 10% loss of crop production in both Schemes 1 and 2 *(WB, 2002)* |
| Cost due to risk of stopping El-Mahsama WWTP | *537,659,769 EGP* | 25% loss of crop production in both Schemes 1 and 2 *(WB, 2002)* |
| Cost due to risk of disposal of remaining harmful sludge waste from WWTP | *948,357 EGP* | 5% loss of environmental quality of Lake Timsah and other scattered benefiting ponds *( Abd El Samie et al., 2009)* |
| Cost due to risk of climate change | *1,709,803 EGP* | 5% loss of crop production in both Schemes 1 and 2, environmental quality of Lake Timsah, other scattered benefiting ponds, and the related socio-economic benefits |
| ***Benefits*** | | |
| 1st agricultural scheme (area of 70,000 feddans eq. to 30,000 ha) with crops (wheat, barley, beans and maize) | *60,000 feddans (net area)* | 90% of the area is cultivated and 10% are fallow lands for services |
| Area covered by each crop:<br>- *Wheat*<br>- *Barley*<br>- *Beans*<br>- *Maize* | <br>*40000 feddans*<br>*10000 feddans*<br>*10000 feddans*<br>*60000 feddans* | <br>Winter crop<br>Winter crop<br>Winter crop<br>Summer crop |
| - Net yields of each crop | 0.9 of the estimated yield | Handling of wastes and loss of yield is ~ 10% |
| Average yield of crop (*in Sinai*):<br>- *Wheat*<br>- *Barley* | <br>*6 ardab/ feddan*<br>*5 ardab/ feddan* | <br>(5-8) ardab/feddan<br>(4-6) ardab/feddan |

| | | |
|---|---|---|
| - *Beans*<br>- *Maize* | *4 ardab/ feddan*<br>*3.3 ton/ feddan* | (3-5) ardab/feddan<br>(3.0-3.5) ton/feddan<br>*(MALR, 2020)* |
| Average selling price of crop:<br>- *Wheat (including secondary animal fodder)*<br>- *Barley (including secondary animal fodder)*<br>- *Beans*<br>- *Maize* | *892 EGP/ardab*<br>*1112 EGP/ardab*<br>*2032 EGP/ardab*<br>*2450 EGP/ton* | (820-970) EGP/ardab<br>(1000-1200) EGP/ardab<br>(2000-2150) EGP/ardab<br>(2200-2600) EGP/ton<br>*(MALR, 2020)* |
| 2nd agricultural scheme (area of 52,000 feddans eq. to 22,300 ha) with cotton, flax, kenaf, and oil crops (peanuts, sesame & soya beans, jojoba, canola and sunflower) | *46,800 feddans (net seasonal area)* | 90% of the area is cultivated and 10% are fallow lands for services<br>*(MALR, 2020)* |
| Area covered by each crop:<br>- *Cotton*<br>- *Flax*<br>- *Kenaf*<br>- *Peanuts, sesame & soya beans (equal areas)*<br>- *Jojoba*<br>- *Canola*<br>- *Sunflower* | *31200 feddans*<br>*11700 feddans*<br>*11700 feddans*<br>*7800 feddans*<br>*11700 feddans*<br>*11700 feddans*<br>*7800 feddans* | Summer crop<br>Winter crop<br>Winter crops<br>Summer crops<br>Winter crops<br>Winter crops<br>Summer crops |
| Average yield of crop (***in Sinai***):<br>- *Cotton*<br>- *Flax*<br>- *Kenaf*<br>- *Peanuts, sesame & soya beans (equal areas)*<br>- *Jojoba*<br>- *Canola*<br>- *Sunflower* | *7.0 kantar/feddan*<br>*4.0 ton/feddan*<br>*7.0 kantar/feddan*<br>*(~1.39, 0.52, and 1.23) ton/feddan*<br>*0.9 ton/feddan*<br>*0.7 ton/feddan*<br>*1.0 ton/feddan* | (5-8) kantar/feddan<br>(3.5-5) ton/feddan<br>(5-9) kantar/feddan<br>Average respectively<br>~0.9 ton/feddan<br>(0.5-0.8) ton/feddan<br>~1.0 ton/feddan<br>*(MALR, 2020)* |
| Average selling price of crop:<br>- *Cotton*<br>- *Flax*<br>- *Kenaf*<br>- *Peanuts, sesame & soya beans*<br>- *Jojoba*<br>- *Canola*<br>- *Sunflower* | *2737 EGP/kantar*<br>*4000 EGP/feddan*<br>*1250 EGP/kantar*<br>*(9462, 12634, and 4431) EGP/ton*<br>*8000 EGP/ton*<br>*58500 EGP/ton*<br>*4795 EGP/ton* | (1900-3200) EGP/kantar<br>(2500-5000) EGP/feddan<br>(600-1800) EGP/kantar<br>Average respectively<br>(4680-10920) EGP/ton<br>(55000-60000) EGP/ton<br>(4000-5385) EGP/ton<br>*(MALR, 2020)* |
| Human health improvements:<br>- *Population of Port Said Governorate*<br>- *Population of Ismailia Governorate*<br>- *Population of Suez Governorate* | *779,587 capita*<br>*1,404,557 capita* | Census of year 2020, Central Agency for Public Mobilization and Statistics (CAPMAS)<br>*(CAPMS, 2021)* |

| | | |
|---|---|---|
| | *771,481 capita* | |
| Human health improvements & risk prevented | *10% sick* | 2500 EGP/sick person |
| | *1% dead* | 20000 EGP/died person |
| Costs of human health improvements (no sicknesses) | *738,906,250 EGP* | (194,896,750+351,139,250 +192,870,250) EGP |
| Costs of human health improvements (no deaths) | *591,125,000 EGP* | (155917400+280911400+1 54296200) EGP |
| Environmental quality:<br>- *Area of Lake Timsah*<br>- *Area of other scattered benefiting surrounding ponds* | *14 km²*<br>*3 km²* | *(Gasiorowski, 2019; ISO, 2019)* |
| Environmental quality:<br>Restoration gain of 17.0 km² of water bodies (1 km² = ~238 feddans) | *18,967,143 EGP* | 300 USD/feddan = 4,686 EGP/feddan<br>*(Khairy, 2004)* |
| Socio-economic benefits:<br>- *Jobs creation and improved livelihood (assumed that annual benefits package for each person is equivalent to about 500 EGP)*<br>- *Products-chain such as (agro-industrial crops processing and marketing, animal meat & dairy productions and trade). Beneficiaries, each receives annual benefits package of 1000 EGP* | *250,000,000 EGP*<br>*1,000,000,000 EGP* | 100,000 jobs created + their families (4 persons in average) = 500,000 beneficiaries<br>Assumed that 1,000,000 beneficiaries from that WWTP and associated agricultural schemes<br>*(Stefea and Circa, 2010; Bateman et al., 2006)* |
| Disposal of agricultural drainage water from the agricultural schemes in irrigating Mahogany Trees (wood forests)<br>*(assumption: 100 tons of Mahogany wood after five years shall be produced, and so on in the following years)* | *188,000,000 EGP*<br>*(starting: Year #5)* | Price of one tone of Mahogany wood is 1,880,000 EGP<br>*(Indiamart, 2021)* |

The CBA was conducted over a time-span of ten consecutive years. Construction and equipping work (CAPEX) of El-Mahsama WWTP is completed already at Year (zero), and it is currently in experimental operation and testing phase. The (OPEX) are considered valid from Year (1) of the analysis whereas, benefits start to accrue one year after, according to agricultural schemes' harvesting, production, processing, and marketing. An annual inflation rate of (9.8% or 10%) was used for equipment and commodities (CBE, 2021). It affected all costs and benefits associated with the operation of El-Mahsama WWTP as well as the agriculture schemes starting from Year 2 up to Year 10.

## V. RESULTS ANALYSIS

A simple cost-benefit model was developed using Micro-soft Excel and populated by the presented calculated and derived data sets shown in Table (1). An economic valuation analysis was conducted for ten years to determine the CBA of applying such WWTP project in Sinai, and to estimate the value of reusing such treated wastewater in agriculture with no risks to the human health nor the environmental quality. Figure (4) shows the estimated costs of all components related to the construction and operation of El-Mahsama WWTP Project as well as the agriculture schemes during 10 years' time-span, in Egyptian Pound.

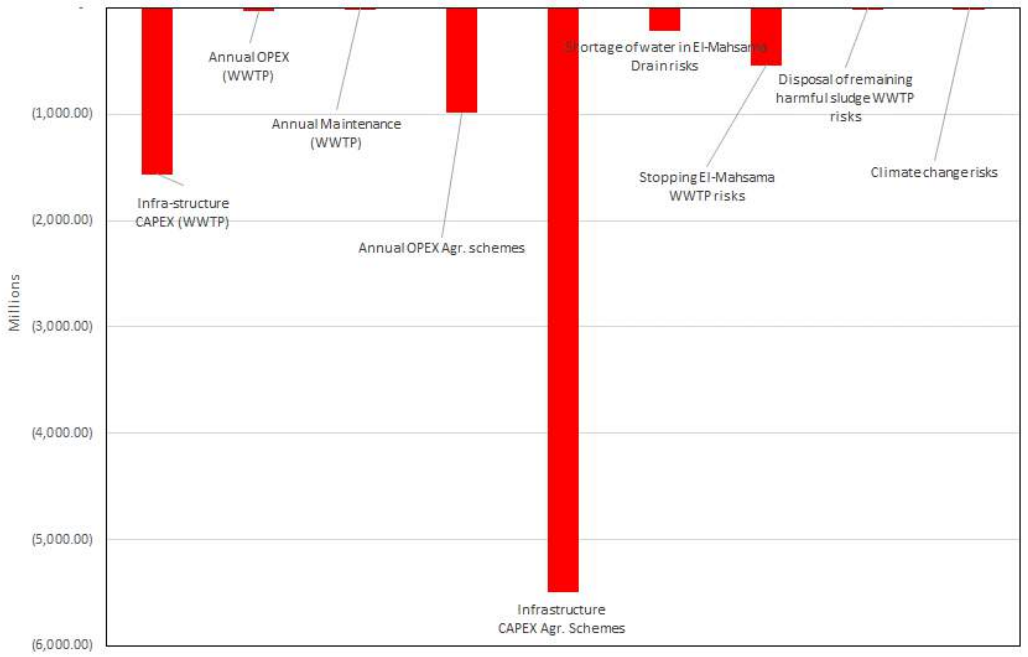


*Figure (4):* Estimated cost components of El-Mahsama WWTP project (EGP)

It is obvious that the highest cost is that associated with the construction of the agriculture schemes (CAPEX) including the installation of the modern irrigation systems, land management services, pumps, pipes, nozzles, valves, civil works, and the other auxiliary works. This is considered reasonable because the area of agriculture schemes exceeds 122,000 feddans, which is equivalent to more than 50,833 hectares. The cost of constructing El-Mahsama WWTP (CAPEX) includes all civil, electrical, mechanical, and electronic works as well as transportation tools comes second as high-cost component. The order of costs from third place to ninth is as follows: annual operation costs (OPEX) for the agriculture schemes, stopping El-Mahsama WWTP risks, shortage of water in El-Mahsama Drain risks, annual operation costs (OPEX) of El-Mahsama WWTP, Annual maintenance cost of El-Mahsama WWTP, Climate change risks, and disposal of remaining harmful sludge WWTP risks, respectively. The cumulative NPV of costs during the ten years of analysis El-Mahsama WWTP Project was estimated at about 23.5 Billion EGP.

On the other hand, Figure (5) shows the estimated benefits of all components related to the operation of El-Mahsama WWTP Project as well as the agriculture schemes during 10 years' time-span, in Egyptian Pounds. Benefits accrued from the 2nd agriculture scheme (cotton, flax, kenaf, peanuts, sesame & soya beans, jojoba, canola, and sunflower), which are cash crops, came on the top with the highest monetary value. Human health benefits came second in order with respect to monetary value, followed by socio-economic benefits, benefits accrued from 1st agriculture scheme (wheat, barley, beans, and maize), mahogany trees production, and environmental quality benefits, respectively. The cumulative NPV of benefits during the ten years of analysis of El-Mahsama WWTP Project was estimated at 44.8 Billion EGP.

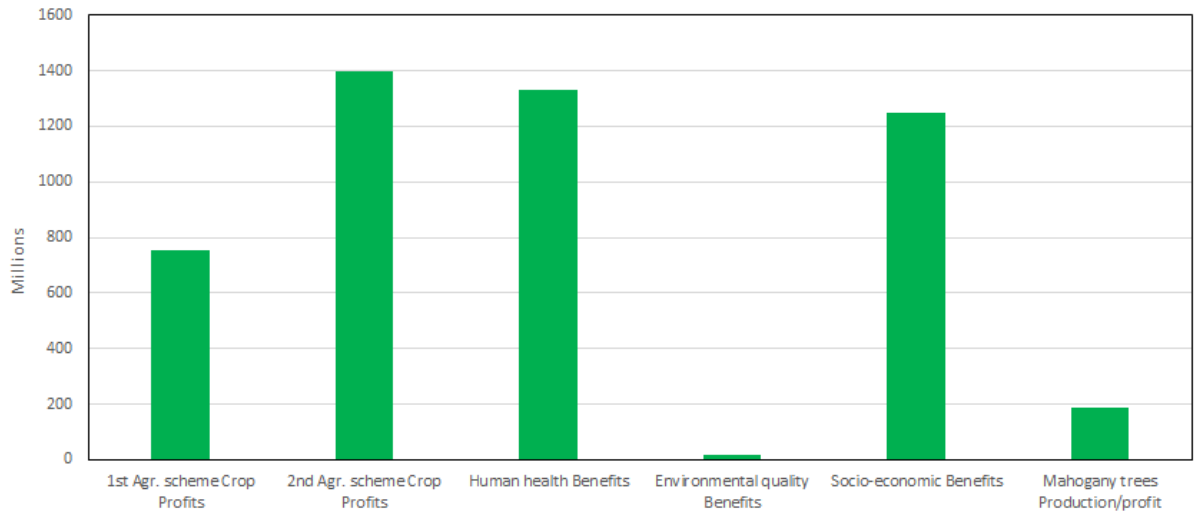


*Figure (5):* Estimated benefits components of El-Mahsama WWTP project *(EGP)*

Figure (6) illustrates the cumulative NPV curves of costs versus benefits of El-Mahsama WWTP Project along ten years of operation. This was associated with safe and sustainable management of the resulting treated wastewater in agriculture purposes, provided that no risks to human health nor environmental quality shall occur. It is important to highlight that in less than three years of operating El-Mahsama WWTP Project; it pays back its full costs and starts to accrue benefits. Furthermore, Figure (7) demonstrates the CBA curve of El-Mahsama WWTP Project operation for ten years. The cost-benefit ration increases with logarithmic rate scoring close to 2.0 in ten years. The relationship between costs and benefits of El-Mahsama WWTP Project could be simulated by a logarithmic trend line with a regression ($R^2$) close to 0.99, as shown in (Figure 7).

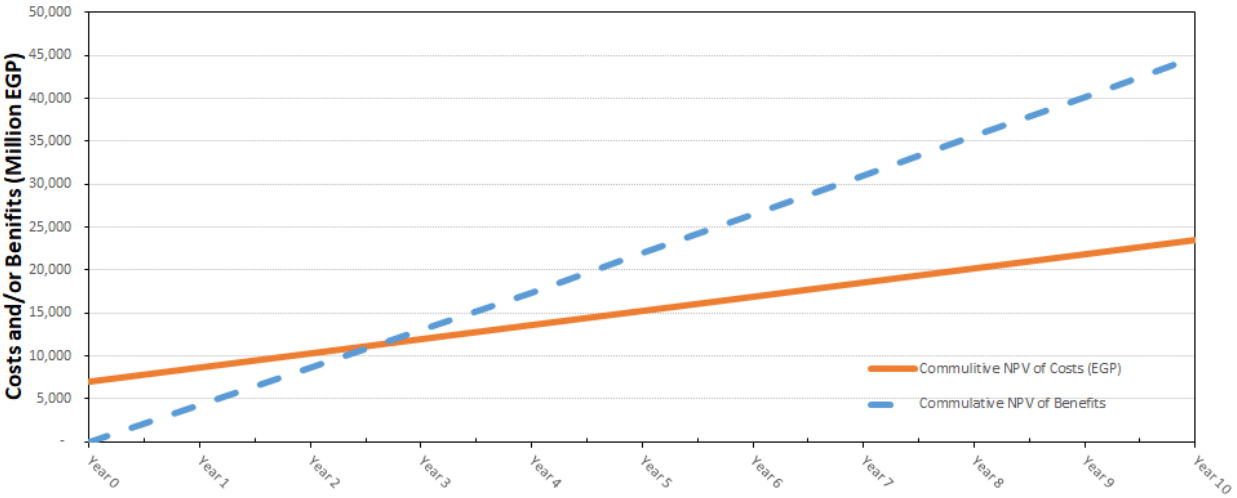


*Figure (6):* Cumulative NPV of costs vs. benefits of El-Mahsama WWTP project (EGP)

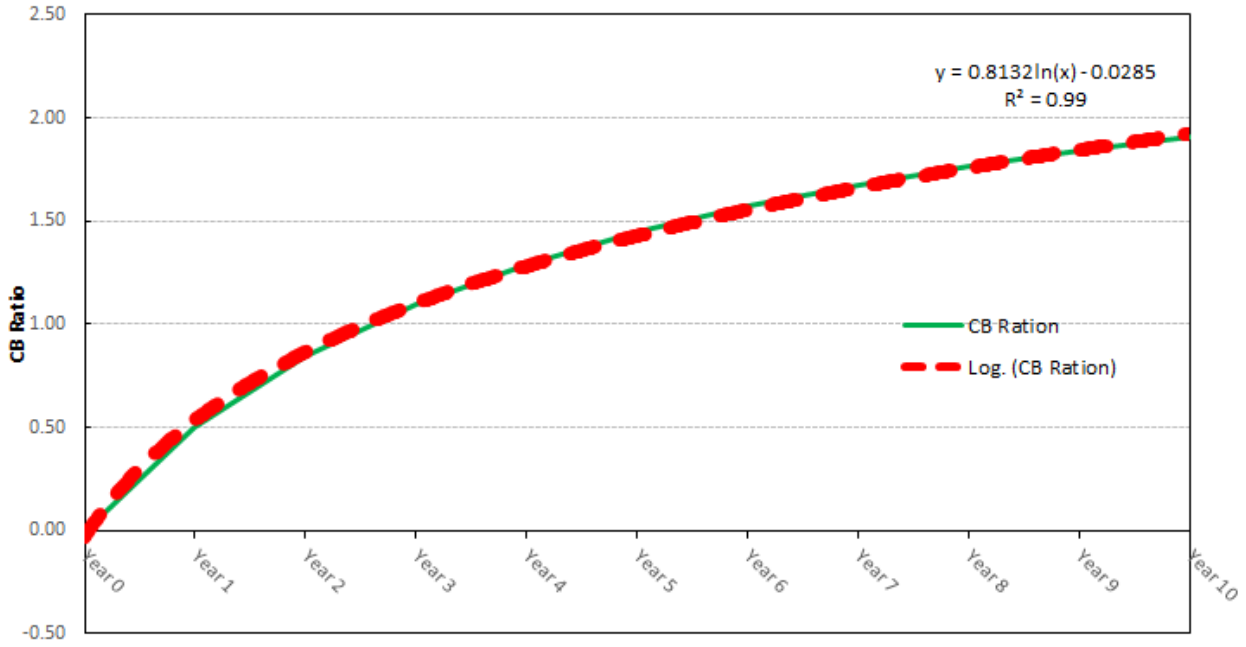


*Figure (7):* CBA curve of El-Mahsama WWTP project with trend-line of logarithmic scale, regression ($R^2$=0.99)

## VI. DISCUSSION

Following the Sustainable Development Goals (SDGs), which include a goal to ensure sustainable water and sanitation for all. Economic valuation of wastewater therefore identifies economic benefits for municipalities associated with wastewater treatment. In addition, Hernández-Sancho *et at.*, (2015) agree with the results of this research paper that wastewater treatment inherits key benefits (environmental and health) that generate positive results and that wastewater management is economically feasible, and produces benefits of higher value than non-action.

This research proved that El-Mahsama WWTP and its associated agricultural schemes accrue benefits of using treated wastewater in agriculture. This benefits were estimated by economic valuation analysis and found almost double the costs in 10 years. This finding is evaluated as "significantly good" by the United States Environmental Program (UNEP), (Hernández-Sancho *et at.*, 2015). Accordingly, this research work encourages and gives confidence to the private sector to invest in wastewater treatment projects, provided that lands can be availed by the government to the investors through concession leases with free utilization for fifty years.

CBA methodology used in this research allows the valuation of costs and benefits of wastewater treatment, safe use, and sustainable management. The findings and detailed results of this research support informed development decision by the policy makers concerning national and regional non-conventional water resources planning and management, particularly in countries suffering from water scarcity.

## VII. CONCLUSION AND RECOMMENDATIONS

This research focused on conducting a cost benefit analysis (CBA) of El-Mahsama WWTP's operation as a good model for wastewater treatment and use in safe and sustainable agriculture purposes, provided that no risks to human health nor environmental quality shall occur. It developed a simple spreadsheet model that simulates costs and benefits associated with the operation of El-Mahsama WWTP. The CBA of operating El-Mahsama WWTP Project for ten years proved that it increases with logarithmic rate scoring

close to 2.0 in ten years. Those results support the decision makers concerning water resources planning and management in Egypt and encourage the private sector as well to invest in wastewater treatment projects. It was proved that expansion in constructing WWTPs in order to utilize its treated wastewater safely and sustainably for irrigating agriculture schemes as well as wood trees is a successful practice. It is evident that wastewater treatment, production and utilization in crop irrigation is viable, cost effective, and has a high positive financial, social and environmental rewards. This practice brings benefits and scores no risks to human health nor environmental quality. The approach and results of this research paper is recommended to be used as a planning guide that can be replicated in other WWTP projects with similar conditions.

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# Electrochemical Obtaining of Thin Rhenium Coatings from Chloride-Sulfate Solutions

*Salakhova E.A., Tagiyev D.B, Jabbarova I.I, Xhankişiyeva N.N., Maharramova A.J & Alizade Y.E*

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## ABSTRACT

The dependence of various factors (current density, temperature, concentration of rhenium, acidity of a solution, nature of an electrode etc.) for electrodeposition of rhenium from chloride-sulfate solutions and obtaining thin rhenium coatings were stidued. The dependence of current yield of rhenium from chloride-sulfate solutions on current density was investigated. It was determined that when current density changes by 10-25 mA/sm$^2$ current yield of rhenium varies between 15-60% and electrolysis must be performed at low current densities to obtain thin rhenium coatings from chloride-sulfate solutions. Electrode position of rhenium at different temperatures was confirmed and it was determined that when the temperature increases, deposition of rhenium becomes easier, and wave height in rhenium curve rises. Studies have determined that high-quality and thin rhenium coatings are produced at 75$^0$C. The electorlyte with the following composition was proposed to obtain thin rhenium coatings from chloride-sulfate solutions. The composition of the electrolyte is as follows (mol/l): 0,01$KReO_4$ +2$H_2SO_4$+2HCl,$i_k$=1–4 mA/sm$^2$ , t=75$^0$C, pH=0,5.

*Keywords:* rhenium alloys, thin coatings, electrochemical deposition, alloys, current density.

*Classification:* For Code: 020399

*Language:* English

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## ABSTRACT

*The dependence of various factors (current density, temperature, concentration of rhenium, acidity of a solution, nature of an electrode etc.) for electrodeposition of rhenium from chloride-sulfate solutions and obtaining thin rhenium coatings were stidued. The dependence of current yield of rhenium from chloride-sulfate solutions on current density was investigated. It was determined that when current density changes by 10-25 mA/sm² current yield of rhenium varies between 15-60% and electrolysis must be performed at low current densities to obtain thin rhenium coatings from chloride-sulfate solutions. Electrodeposition of rhenium at different temperatures was confirmed and it was determined that when the temperature increases, deposition of rhenium becomes easier, and wave height in rhenium curve rises. Studies have determined that high-quality and thin rhenium coatings are produced at 75°C. The electorlyte with the following composition was proposed to obtain thin rhenium coatings from chloride-sulfate solutions. The composition of the electrolyte is as follows (mol/l): 0,01KReO$_4$+2H$_2$SO$_4$+2HCl,$i_k$=1−4 mA/sm² , t=75°C , pH=0,5.*

*Keywords:* rhenium alloys, thin coatings, electrochemical deposition, alloys, current density.

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## I. INTRODUCTION

The future development of science and technology is possible thanks to the study of new nanomaterials with new properties and creation of devices on their basis, which meet modern requirements. For this purpose, the production of new semi-conductor nanomaterials and their practical application are of great importance [1-3]. Presently, there are different methods for producing nanomaterials among which electrochemical method is considered to be the most effective and promising for obtaining these materials. Due to the high level of development in science and technology the production of high efficient materials from high quality and existing materials using less material is one of the topical issues of a modern life. For this purpose recently, production of nanoparticles of several substances, their physical and chemical properties allows using them as a promising material in different fields of a modern technology. In this regard, there is a growing interest in electrochemical production of nano films. Electrochemical method has its own positive features. It is possible to perform electrolysis process with accuracy and regulate the thickness of the coating using electrochemical method. To produce these substances there is a wide range of methods that electrochemical method ranks among the highest. Rhenium has a high melting temperature, mechanical durability, hardness and high resistance. Its corrosion resistance and high thermoelectric properties opens wide opportunities for its application in electrical engineering and radio engineering [4-12].It is used in electronics – for the preparation of elements of electron lapms, thermopairs,

electrocontacts in electrical engineering. It is also used in the preparation of rocket body, some elements of reactors in aerospace engineering. Therefore, the development of new methods of producing rhenium nano films is of great interest [13-15].One the main issues in the production of rhenium is to obtain high-purity rhenium. Electrochemical method is the most effective method for this purpose. The main aim of the research work is to select optimum mode and electrolyte to produce thin rhenium films from chloride-sulfate solutions.

## II. METHODS

The following reagents were used to perform the research work: $KReO_4$ (chemically pure), $H_2SO_4$ (chemically pure), HCL (chemically pure), Polarization measurements were recorded using platinum cathode with a surface are of 0,15 $sm^2$. In the experiments silver - chlorine electrode was used as a reference elctrode, but platinum wire was used as an auxiliary electrode. Polarization measurements were recorded using platinum cathode with a surface area of 0,15 $sm^2$. The kinetics of deposition of rhenium was studied using cyclic voltammetric methods and IVIUMSTAT electrochemical analyzer – potentiostat supplied with a computer. Each experiment was performed twice for the accuracy of the results. The temperature was regulated with ± 0,1°C of accuracy using U-10 thermostat. An electrolyzer supplied with a special glass and burette to collect gas released during electrolysis, was used to determine current yield of hydrogen. Current yield was determined by weight method using copper coulombmeter and calculated with regard to the composition of the deposit. Phase composition of a surface structure of rhenium cathode deposits was determined using Tesla BS-301 electron microscope and «Cotece» M-46 microprobe.

## III. EXPERIMENTAL PART

Reduction of rhenium from acid solution was studied by many scientists and it was determined that reduction of rhenium goes in stages [8 - 12], during electrolysis rhenium oxides are formed and hydrogen is released. In our previous research works we have provided extensive information on the deposition of rhenium from sulfate, chloride, chloride-borate, chloride-sulfate and alkali solutions [8-12]. The main aim of the research work is to select optimum mode, electolyte and to study anodic processes in detail to produce thin rhenium films from chloride-sulfate solutions. Little information is available in literature on rhenium deposition from chloride-sulfate solutions [1-5]. Figure 1 shows the polarization curves of the rhenium deposition in various concentrations from chloride-sulfate solutions. In polarization curves of rhenium two different waves are observed: one is at + 0.45 V potential and the second is at + 0.30 V levels. The existence of these waves can be explained by gradual mechanism of reduction of perrhenate ion and as a result the formation of rhenium oxides as an intermediate product is observed. In our view in cathodic process the formation of $ReO_3$ and $ReO_2$ is explained by gradual mechanism of reduction process of perrhenate ion till rhenium and confirmed by the formation of red and blue deposits.

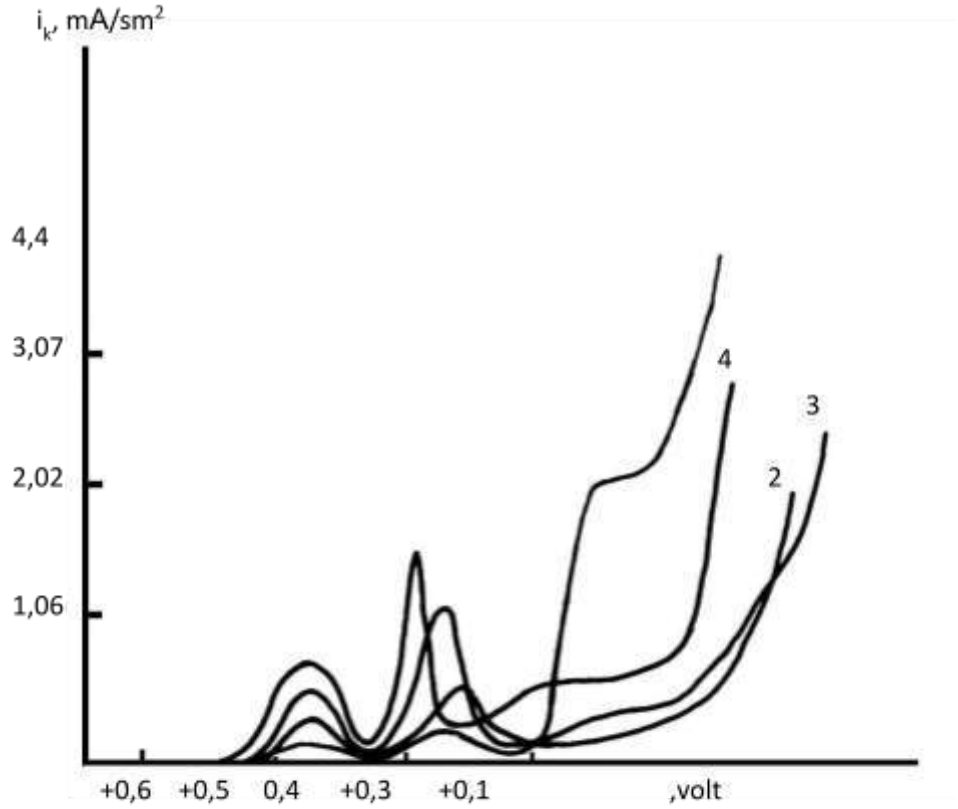


*Fig.1:* Cathodic polarization curves of platinum electrode in solutions containing 1,5 $H_2SO_4$ and 1,5 HCl various concentrations of ammonium perrhenate by temperature (°C) 75, concentration of electrolyte $KReO_4$. (mol/l): 1—0,05, 2 – 0,06, 3 – 0,07; 4 – 0,08

It is supposed that reduction of perrhenate ions for the first wave the cathodic process occurs by the following reaction:

$$ReO_4^- + 2H^+ + e \rightarrow ReO_3 + H_2O \quad (\text{I stage})$$

$$E_1 = E_1^0 + 0{,}058 \lg a_н \cdot a_н^2 \qquad E_1^0 = +0{,}4 \text{ b}$$

The formation of the second wave can be explained by the reduction reaction of $ReO_3$ to $ReO_2$.

$$ReO_3 + 2H^+ + 2e \rightarrow ReO_2 + H_2O \quad (\text{II stage})$$

$$E_2 = E' + \frac{0{,}058}{2} \lg a_н^2 \qquad E = +0{,}6 \text{ B}$$

The last stage is the reduction of $ReO_2$ to elementary rhenium and expressed by the following reaction:

$$ReO_2 + 4H^+ + 4e \rightarrow Re + 2H_2O \quad (\text{III stage})$$

$$E_4 = E_4^0 + \frac{0{,}058}{4} \lg a_н^4 \qquad E_4 = +0{,}252 \text{ b}$$

Sharp increase in a current density observed at a constant potential (+ 0.1 V) is due to hydrogen reduction:

$$E_\Sigma = E_\Sigma^0 + \frac{0{,}058}{7} \lg a_м^2 \cdot a_н^8 \qquad E = +0{,}36 \text{ B}$$

Due to essential sorption of hydrogen by rhenium this shows the properties of hydrogen electrode. Very low tension of hydrogen [1 - 5] on rhenium is due to significant sorption of hydrogen atom by rhenium. As it is seen hydrogen which saturates rhenium, activates it due to the formation of non-constant hydride which is easily converted

first to rhenium oxide, and to higher type oxides and then due to the its oxidation.

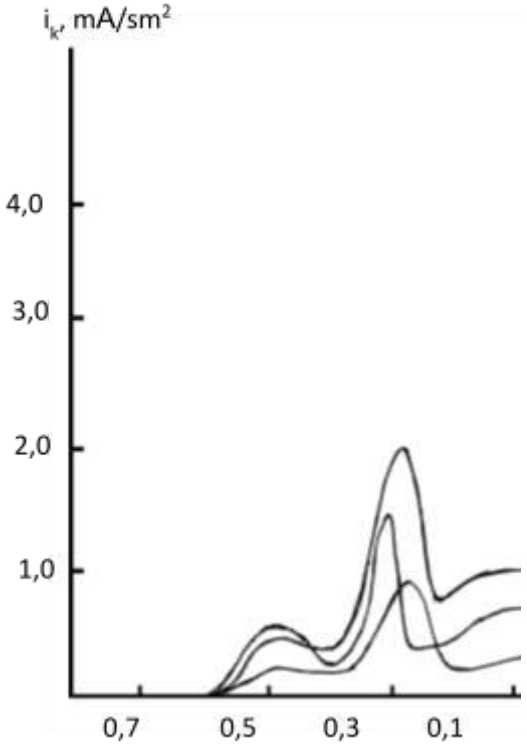


*Fig.2:* Cathodic polarization curves rhenium on platinum electrode in solutions containing electrolyte (mol/l): 0,05 KReO4+ 1,5 $H_2SO_4$ + 1,5 HCl + 0,01 $(NH_4)_2SO_4$by different temperature (°C) 1-25; 2 – 45; 3 – 80.

Stationary potential of rhenium in chloride-sulfate solutions is + 0.3 V. To study the kinetics of rhenium deposition potentiostatic and cyclic voltammetric methods were used and polarization curves were plotted. Electrodeposition of rhenium from chloride-sulfate solutions at different concentrations was studied and silvery-gray, crystalline rhenium coating with a thickness of 2-6 mkm which covers the cathode evenly is obtained on the electrode. Deposition mechanism of rhenium depends on the composition of an electrolyte, electrolysis condition, surface state of an electrode, temperature, current density and acidity of a solution. Electrodeposition of rhenium from chloride-sulfate solutions and form and quality of films depends on the temperature. For this purpose, electrodeposition of rhenium at different temperatures and polarization curves were plotted.Figure 2 shows cyclic voltammetric polarization curves of dependence of electrodeposition of rhenium from chloride-sulfate solutions on temperature. During electrolysis temperature ranged between 20-90°C. As figure shows at a higher temperature rhenium is easily deposited, the length of a wave on rhenium curve rises. According to researches it was determined that higher quality and thin rhenium films are obtained at 75°C. To clarify electrodeposition mechanism of rhenium from chloride-sulfate solutions temperature-kinetic method was used. Polarization nature in cathode process was determined by using this method and $\log_к$ – 1/T diagram at different constant values of cathode potential was plotted.

According to straight line dependence at a constant potential of cathode effective activation energy ($A_{eff.}$) of electrode process was calculated using the following equation

$$\log_{\kappa} = \text{cons.} - \frac{A_{eff.}}{2{,}303RT}$$

here $i_{\kappa}$ –current density, R – gas constant, T – absolute temperature, $A_{eff.}$ – effective activation energy.

The results show that if the dependence of logarithm of current density of cathode potential on 1/T is linear, the dependence of an effective activation energy on cathode potential will be accompanied by polarization and the rate of cathode process is characterized by ion diffusion on cathode surface. It was determined that the increase in the temperature from 20°C to 80°C rises cathodic polarization of rhenium, when electrode potential shifts to a negative side activation energy decreases sharply, then it remains constant.

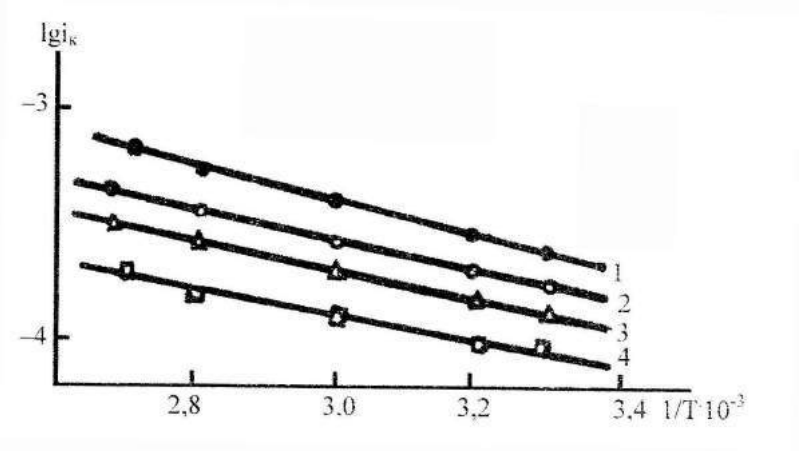


*Fig.3:* Dependence of lg $i_k$ from 1/T at Pt electrode by potentials (1)-0,65, (2)-. Elektrolyte (mol/l): 0,5 $NH_4$ $ReO_4$ + 1,5 HCl + 1,5 $H_2SO_4$.+ 0,01 $(NH_4)_2SO_4$ by potenceals (v): 1 –(+0,50); 2 – (+0,54); 3 – (+0,56); 4 – (+0,59)

The results show that electrodeposition of rhenium from chloride-sulfate solutions occurs first with electrochemical polarization, then with mixed kinetics, and transforms to concentration polarization. The dependence of current yield of rhenium in electrolyte on temperature, current density, acidity of a solution was studied.

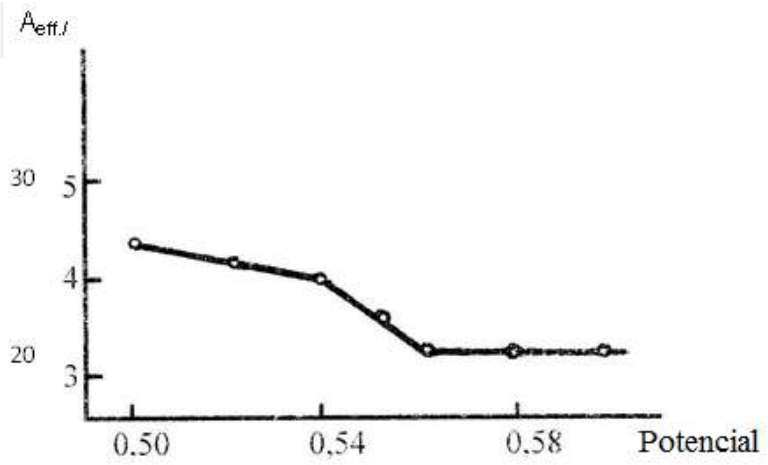


*Fig. 4:* De[endence of activation effective energy ($A_{eff.}$) from value of potential on the Pt electrode in electrolyte (mol/l) : 0,5 $NH_4$ $ReO_4$ + 5 HCl + 5 $H_2SO_4$.+ 0,01 $(NH_4)_2SO_4$

Table 1 shows the dependence of current yield of rhenium on the acidity of solution. When acidity increases, current yield of rhenium first increases, then at 2,0 mA/sm² current density it decreases and high-quality rhenium films are obtained in pH=1,5 and current yield is found to be 48 %. Thus, as the concentration of HCl in the solution increases, the process of rhenium reduction becomes easier as rhenium dissolves. When the concentration of HCl acidity increases, rhenium forms more stable complex compound in the solution. Depending on acidity effect the properties and form of rhenium films change. As the table shows when the concentration of HCl acid in solution ranges between 1 mol/l to 4 mol/l, the current yield of rhenium varies from 59% to 86%. When the concentration of HCl is 3mol/l, current yield of rhenium increases from 56% to 70% due to the increase in current density. When current density is 10 mA/sm², and concentration of HCl is 1,5 mol/l, dark gray, lustrous, evenly distributed on the surface rhenium film with the thickness of 5 mkm can be produced. At the same current density current yield of rhenium is found to be 75% and with further increase in current density the form and quality of rhenium film becomes worse. Therefore, further experiments were performed in the solution containing 3mol/l of HCl.

*Table 1:* Dependence of current yield of rhenium on the acidity of solution. Electrolyte content (mol/l): 0,05 $KReO_4$ + 1,5$H_2SO_4$ , t=75°C.

| Concentration of HCl, mol/l | $İ_k$, mA/sm² | Current yield, Re % | Form of coatings |
|---|---|---|---|
| 1 | 10 | 59 | Grey, uneven, congeneric |
| 1,5 | 10 | 70 | Dark-grey, smooth, congeneric |
| 2 | 10 | 75 | Dark-grey, shiny, congeneric, |
| 2,5 | 10 | 86 | Grey, uneven, shiny |

As electrolysis occurs at acid medium, hydrogen ions are separated in solution and one part of current is consumed to the separation of hydrogen, the other part is consumed to the separation of rhenium. During deposition of rhenium certain amount of hydrogen is also separated in a cathode and partial polarization curves were plotted to study the processes on electrodes in detail. As it is known as several electrochemical reactions occur on an electrode surface, general polarization curves cannot characterize the rate of any process. Thus, it is found to be a total curve and expresses all electrochemical reactions on electrode surface totally. In this case such complex curve is divided into partial curves. The amount of any current consumed for any reaction is calculated according to the obtained substance: current consumed for the separation of hydrogen is calculated according to the gas volume released during electochemical process. To clarify the kinetics of such mixed electrochemical reactions electrolysis process is performed in a special electrolyzer. Special device is used to collect gases released on electrode. To calculate the amount of a current consumed for the separation of substance on electrode this device is connected to copper coulombmeter. As partial curves show total curve for rhenium is obtained at -0,05 V potential. But the separation of hydrogen in this solution occurs at -0.12 V potential, reduction of rhenium occurs at -0.11V potential. In electrolysis oxidation of water molecule and intensive separation of hydrogen on rhenium occurs at a separation potential of rhenium. The amount of hydrogen separated intensively depends on the composition of solution and current density. Depending on the effect of these factors the amount of hydrogen

separated on eelctrode varies. The property and structure of rhenium deposit changes depending on the amount of separated hydrogen. Thus, a part of hydrogen separated during electrolysis sticks to rhenium surface, changes its property and causes defects in its structures. Therefore, to study the mechanism of electrochemical deposition of rhenium from chloride-sulfate solution the effect of all factors (electrolyte composition, current density, acidity, temperature, electrode material) which impact on electrolysis process must be considered in research work.

As it is known the form and quality of rhenium film also depends on a current density. When current density varies between 10 mA/sm² - 20 mA/sm² in solution during electrolysis, current yield of rhenium and form of rhenium film change. This dependence is presented in the table 2.

*Table 2:* Dependence of current yield of rhenium on current density
Composition of electrolyte (mol/l): $1,5H_2SO_4+1,5HCI$

| Concentration of $KReO_4$, mol/l | $i_k$, mA/sm² | Current yield, Re % | Tempe-rature, °C | Form of coatings |
|---|---|---|---|---|
| 0,01 | 10 | 30 | 75 | Greyish-blue, uneven |
| 0,01 | 15 | 54 | 75 | Light-grey, congeneric unsmooth |
| 0,01 | 20 | 58 | 75 | Light-black, matte, uneven |
| 0,01 | 25 | 45 | 75 | Dark-grey, unsmooth, congeneric |

As the table shows at 10 mA/sm² current density a light-blackish, unlustrous, rhenium film distributed evenly on platinum electrode with thickness of 5 mkm and current yield of 30% was obtained from 0,01mol/l $KReO_4+1,5H_2SO_4+1,5HCl$ solution at 75°C. temperature. It was determined that when current density increases, i.e. at 2 mA/sm² of current density, a dark-gray, uneven rhenium film distributed unevenly on a platinum electrode with a thickness of 5 mkm and current yield of 28% was obtained.

The dependence of current yield of rhenium from chloride-sulfate solutions on current density was studied. It was defined that when current density 10-25 mA/sm² changes, current yield of rhenium varies between 15-60%. When current density is 20 mA/sm², i.e. at higher current densities current yield of rhenium reduces. This is explained by hydrogen release at high current densities. It was found out that to produce thin rhenium films from chloride-sulfate solutions electrolysis must be performed at low current densities. The dependence of electrodeposition of rhenium from chloride-sulfate solutions on rhenium concentration on platinum electrode was studied using voltammetric method. Figure 3 shows these polarization curves. By performing electrolysis on a platinum electrode it was determined that anodic polarization curve characterizes anodic dissolution of rhenium on electrode and the process occurs at a positive potential.

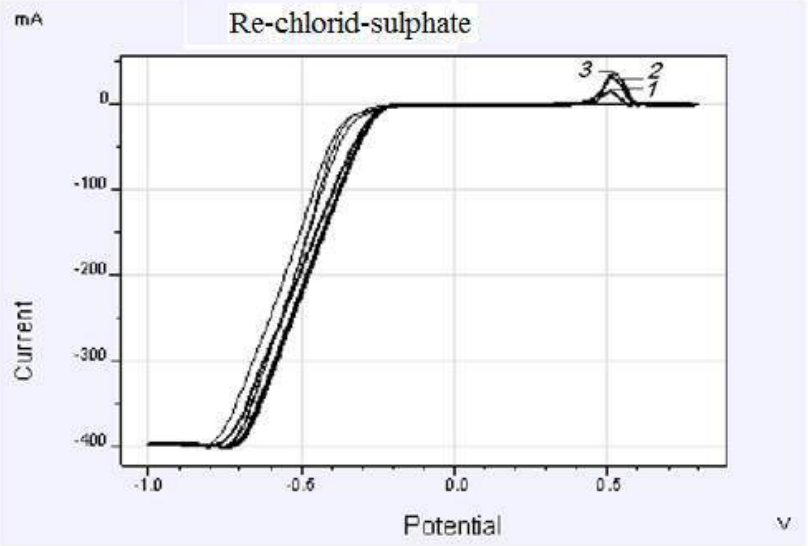


*Fig. 5:* Cyclic polarizing curves of rhenium on Pt electrode in the electrolyte containing (mol/l): (1) $6.9 \cdot 10^{-3}$ $KReO_4$ + 2 HCl+$2H_2SO_4$ ;, pH=0.5, T=75 ° (scan rate $V=0,005VS^{-1}$ )

Electrodeposition of rhenium also depends on the material of an electrode. Figure 8 shows the study of rhenium deposition on different electrodes. Kinetics and mechanism of electrochemical processes depend on an electrode surface, its polishing degree, lustre and so on. Depending on an electrode material any process occurs at various stages. Electrodeposition of rhenium from chloride-sulfate solutions was studied on platinum and rhenium electrodes. In both cases there were no any changes in the form of polarization curves, and this shows that rhenium deposition on both platinum and rhenium electrode occurs by the same electrochemical reaction. By performing electrolysis both on platinum and rhenium electrodes it was determined that reduction of perrhenate ions on rhenium electrode occurs at more positive potential, i.e. electrochemical reduction of rhenium becomes easier. Electrodeposition of rhenium from chloride-borate solutions was also studied. Figure 5 presents cyclic voltammetric polarization curves of electrodeposition of rhenium from chloride-borate solutions.

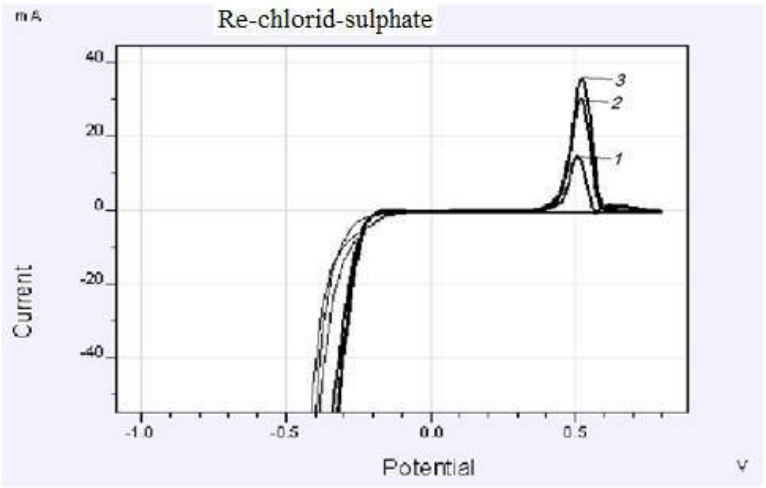


*Fig. 6:* Cyclic polarizing curves of rhenium on Pt electrode in the electrolyte containing (mol/l): (1) $6.9 \cdot 10^{-3}$ $KReO_4$ + 2 HCl+$2H_2SO_4$ ;, pH=0.5. temperatur °C; 1-25, 2-45, 3-75 .(scan rate $V=0,005VS^{-1}$ )

As figure shows rhenium deposition from chloride-sulfate and chloride-borate solutions occurs at various potentials and there are certain differences and changes both in cathodic and anodic polarization curves.

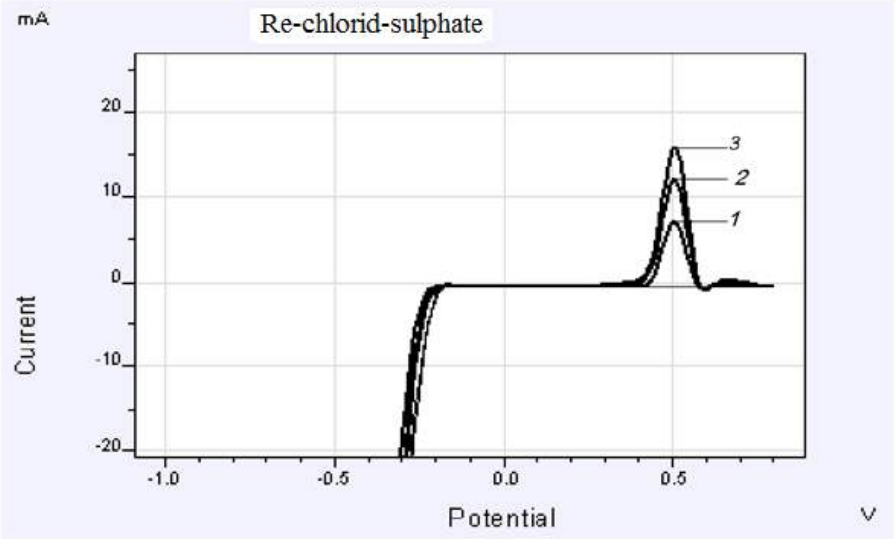


*Fig. 7:* Cyclic polarizing curves of rhenium on Pt electrode in the electrolyte containing (mol/l): (1) $6.9 \cdot 10^{-3}$ $KReO_4$ + 2 HCl+2$H_2SO_4$ ; 2-0,015$KReO_4$+2HCl +2$H_2SO_4$; 3-2$KReO_4$+2HCl +2$H_2SO_4$, pH=0.5. temperature 75 °C; (scan rate $V=0,005VS^{-1}$ )

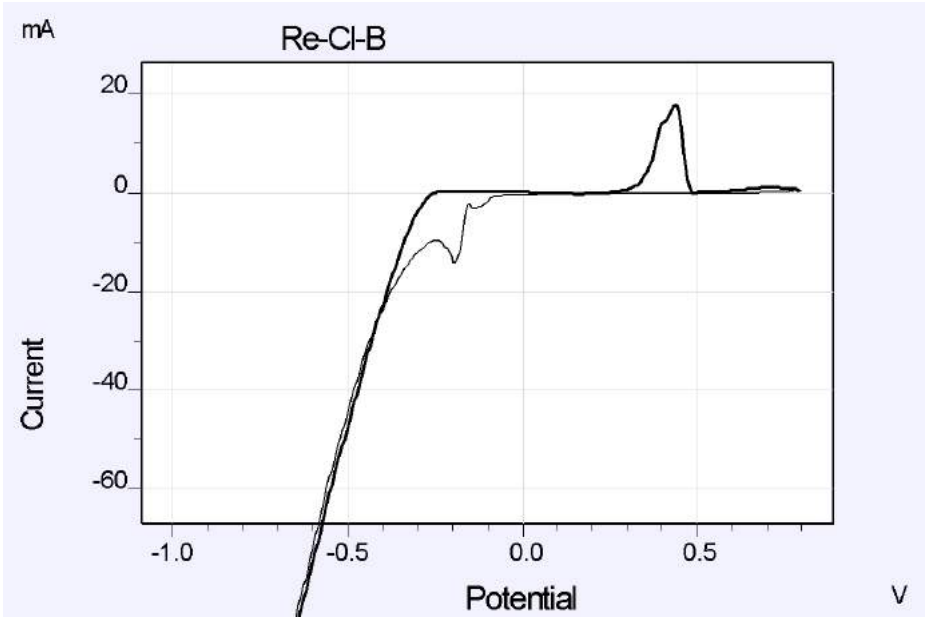


*Fig. 8:* Cyclic polarizing curves of rhenium on Pt electrode in the electrolyte containing (mol/l): (1) $6.9 \cdot 10^{-3}$ $KReO_4$ + 2 HCl+2 H3BO3; pH=0.5. temperatur 75°C; (scan rate $V=0,005VS^{-1}$ )

Thus, according to the experiments the electrolyte with following composition was proposed to produce thin rhenium films from chloride-sulfate solutions. Electrolyte composition is as follows (mol/l):0,01$KReO_4$+1,5$H_2SO_4$+1,5HCl,$i_k$=1–4mA/ $sm^2$ , t=75°C, pH=0,5

## IV. CONCLUSIONS

1. The dependence of current yield of rhenium from chloride-sulfate solutions on current density was studied. It was determined that when current density 10-25 mA/sm² changes, current yield of rhenium ranges between 15-60%. It was defined that electrolysis must be performed at lower current densities to obtain thin rhenium films from chloride-sulfate solutions.
2. Electrodeposition of rhenium at different temperatures was studied and it was defined that at higher temperatures rhenium deposition becomes easier, and wave height in rhenium curve rises. Studies have determined that high-quality and thin rhenium films are obtained at 75°C and optimum temperature was found to be 75°C.
3. Based on the experiments the electrolyte with the following compositon was proposed to obtain thin rhenium films from chloride-sulfate solutions. The composition of an eletrolyte is as follows: (mol/l): 0,01K $ReO_4$+2$H_2SO_4$+2HCl, $i_k$=1-15mA/sm², t=75°C, pH=0,5

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# Seismic Time-Depth Conversion for Reservoir Depth Determination and Digital Well Log Interpretation of Fluids in an X-Field of the Niger Delta, Southern Nigeria

*Ogini Arthur A & Airen Osariere J.*

*University of Benin*

## ABSTRACT

Seismic time-depth conversion for reservoir depth determination and digital well log interpretation of associated fluids was carried out in an X-field of the Niger delta with a view to establishing time-depth functions, in the vicinity of control wells, that could be used to estimate the reservoir depths and thickness of a pay zone (Horizon M10) elsewhere in the field prior to drilling. A combination of check-shot data and time picks on seismic section was used to generate time-depth functions from which depths to the top and bottom of the reservoir in the vicinity of two wells were established. An integrated multi parameter well log analysis was used to interpret the reservoir fluids within the selected horizon. Results showed that the top of Horizon M10 in the vicinity of well-7 was 5230 ft while its bottom was estimated to be 5327 ft with thickness; 97 ft. Around Well-4, the horizon was calculated to be 5108 ft at the top and 5194 ft at the bottom, its thickness was found to be 86 ft. Comparison with wire-line log depth recordings in the reference Wells showed that depth estimates from the seismic time-depth conversion fell well within the reservoir limits even though the reservoir thickness seem to be slightly underestimated. It was concluded that the seismic time-depth conversion for this X-field has an acceptable limit of accuracy and hence reliable for application elsewhere in the X-field. The fluid interpretation of the reservoir was found to be gas sands around well-7 and oil sands in the vicinity of well-4.

*Keywords:* seismic time-depth conversion, digital well log interpretation of reservoir fluids.

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*Author 2:* Department of Physics, University of Benin, Benin City, Edo State Nigeria.

## I. INTRODUCTION

The usefulness of seismic data to solve real-time hydrocarbon exploration and production problems lies in the accuracy of the seismic time-depth conversion, while the processed seismic data is visually enhanced, it is usually in time domain and interpretation on the other hand is in the distance or depth domain (Mohamad et., al 2013; Laurence and Rachel, 2005). The means to achieving dependable time-depth conversion is contained in a body of algorithm referred to as velocity analysis wherein the necessary information or data for velocity analysis could be derived from sonic logs, check shots, Vertical Seismic Profiling (VSP) and Uphole seismic surveys (Hitlerman, 1977; Boise, 1978). The significance of velocity models, which may be highly inhomogeneous in time and space, are not limited to basic processing operations like Normal Moveout (NMO) correction and migration, but also in their special application to time-depth conversion during seismic interpretation (Sheriff and Geldart, 1995; Dobrin and Carl, 1988; Kearey and Brooks, 1991). Seismic interpretation is basically the picking of two way travel times of reflection events corresponding to horizons of strong acoustic impedance on a seismic section which may later be analyzed as faults/folds, major subsurface discontinuity or lithologic contrast often displayed on time maps. To know the depths at which these time events are actually located for a cost effective drilling/exploitation of targets, an

accurate time-depth conversion for the field in question is necessary (Mc Quillin et al., 1979). Once the depth at the top and bottom of any horizon of interest has been established to an acceptable level of accuracy, it is simple to determine its thickness by simple subtraction. Ogbamikhumi and Aderibigbe (2019) noted that there is a certain level of uncertainty inherent in seismic time to depth conversions in oil fields which calls for statistical analysis of the best method suitable in the Niger Delta. On that note, Sofola (2018) had identified an uncertainty of less than and over 50 ft depending on the depth of interest, using instantaneous gradient velocity function and polynomial methods respectively. This paper hopes to provide a case example of seismic time-depth conversion in an X-field of the Niger Delta using the polynomial function method, and the subsequent interpretation of associated reservoir fluids using the physical relationships between the logged parameters and the reservoir static/dynamic properties.

LOCATION OF STUDY AREA

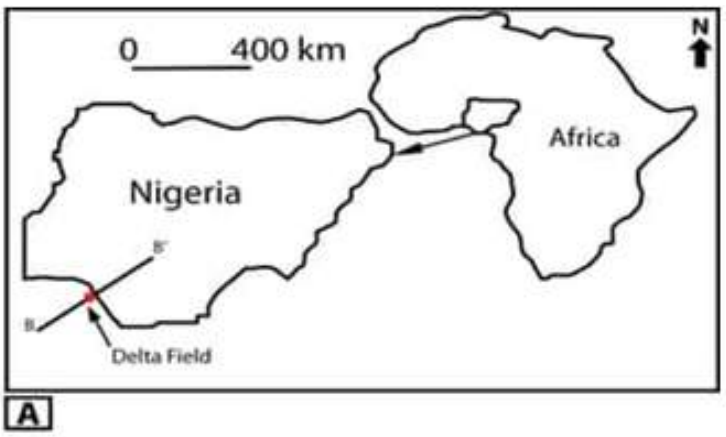



*Figure 1:* (a) the Niger delta in relation to Nigeria and the African continent; (b) Map of the Niger delta after (STRATFOR.com)

The Niger delta is located on the continental margin of the Gulf of Guinea in equatorial West Africa between latitudes (3° and 6°) N and longitudes (5° and 8°) E, it extends from the planes of southern Nigeria into the continental shelf of the Atlantic ocean in the south-south geopolitical region of the country. The Niger delta is Nigeria's major petroleum province hence has attracted oil exploration and exploitation activities since the discovery of commercial petroleum crude in 1956.

## II. MATERIALS AND METHOD

*Materials:* The following materials were used: Base map showing the position of 3 wells, 3-D polarity display seismic section of an X- field in the Niger Delta oil province, point shots (T-Z) scatter data for the 3 wells and reflection time picks for the chosen horizon (M10). Well-log suites (gamma ray, density, sonic, resistivity) furnished with porosity and hydrocarbon saturation information.

*Method:* Check shot (t-z) data was used to derive time-depth function which was used to convert two-way reflection times to depths. Microsoft Excel scatter and function developer was used for the associated plots. Using in-lines and cross-lines (bines and stacks), the horizon of interest was mapped across the field. The horizon of interest (M10) was carefully traced along bins and stacks followed by two-way reflection time picks at the top and bottom of the horizon and subsequently posted to their corresponding acquisition grids. Using the t-z function, two-way times at the top and bottom of the horizon were converted to depth and their thicknesses derived by subtraction.

## III. CALCULATIONS

The t-z function for well-7 as determined from the graph (figure 2) was given by

$$t = 0.296489z + 14.93 \qquad (1)$$

t = two-way seismic reflection time in milliseconds (ms)

z = depth in feet (ft)

Now, horizon M10 top corresponds to 1565.714 ms on seismic two-way reflection time; the depth equivalent is got by transforming eqn. (1)

Thus

$$z = (t - 14.93)/0.296489 \qquad (2)$$

Where z = seismic depth equivalent of two-way reflection time

t = two-way seismic reflection time at horizon M10 top

Substituting for 't' in (2);

$$z = (\frac{1565.714-14.93)}{0.296489}$$

$$= \frac{1550.784}{0.296489}$$

$$= 5230.494 \text{ ft}$$

This is approximated to 5230 ft.

Also, horizon M10 bottom is identified at 1594.286 ms on the seismic section.

thus,

$$z = \frac{(1594.286-14.93)}{0.296489}$$

$$= 5326.86 \text{ ft}$$

$$= 5327 \text{ ft approx.}$$

The horizon thickness ($h$) is got by subtracting the top depth from the bottom depth;

$$h = 97\ ft\ .$$

Again;

The time-depth function for well-4 (figure 3) is;

$$t = 0.301096z + 7.632 \qquad (3)$$

$t$ is the seismic reflection time at horizon M10 top

$z$ is the depth equivalent of seismic reflection time at horizon M10 top

Thus,

$$z = (\frac{t-7.632)}{0.301096} \qquad (4)$$

Substituting for '$t$' in (4) where $t$ was picked at 1545.713 ms

$$z = \frac{(1545.713-7.632)}{0.301096}$$

$$z = 5108.2744$$

This is approximated to 5108 ft.

Also, horizon M10 bottom was picked at 1571.428 ms two-way seismic reflection time and by applying equation (4), the seismic bottom depth equivalent of horizon M10 is;

$$z = (1571.428 - 7.632)/0.301096$$
$$= 5193.679$$
$$\sim 5194 \text{ ft.}$$

The thickness $h$ was got by subtraction;

$$h = 5194 - 5108; \quad = 86 \text{ ft approx.}$$

## IV. RESULT AND DISCUSSION

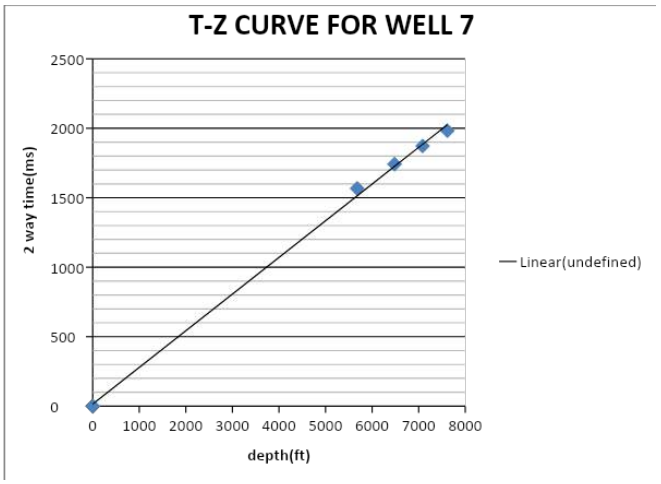


*Figure 2:* Time-depth graph for well-7

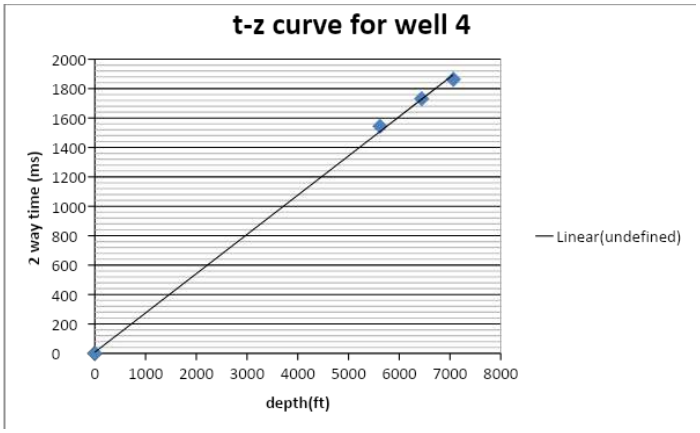


*Figure 3:* Time-depth graph for well-7

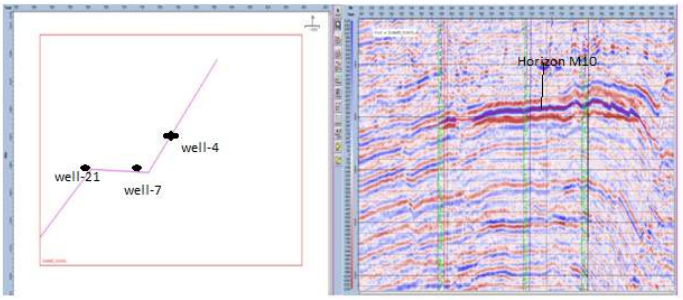


*Figure 4:* Map and Seismic Views of Reservoir and Wells

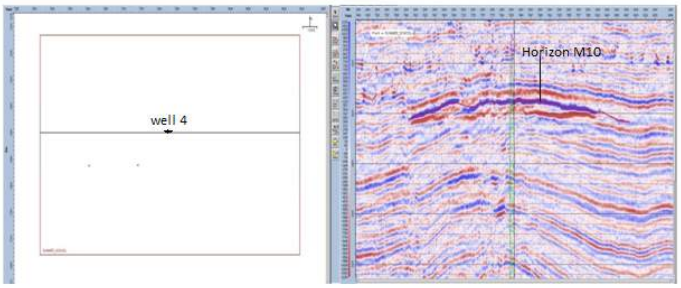


*Figure 5:* Map and Seismic In-line Views of Horizon M10 in the Vicinity of Well-4

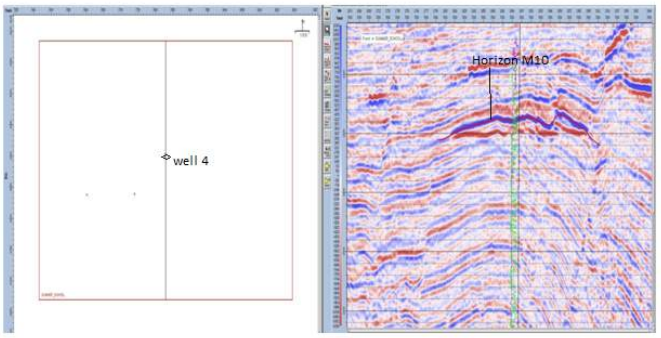


*Figure 6:* Map and Seismic Cross-line Views of Horizon M10 in the Vicinity of Well-4

*Table 1:* Seismic Time-Depth Conversion Results

| Well Reference | WELL-7 | WELL-4 |
|---|---|---|
| Horizon Bottom (ft) | 5327 | 5194 |
| Horizon Top (ft) | 5230 | 5108 |
| Reservoir Thickness | 97 (ft) | 86 (ft) |

*Table 2:* Digital Log Extracts of Horizon

| Depth (ft) | CALP | FDC (g/cc) | RT (Ωm) | GR (API) | POR | SH | SW | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 5174.5 | 11.91 | 2.250 | 1.976 | 85.20 | 0.207 | 0.154 | 0.947 | Shale/HC |
| 5176.5 | 11.91 | 2.210 | 1.930 | 92.39 | 0.194 | 0.118 | 0.882 | Shale/HC |
| 5180.5 | 11.56 | 2.290 | 2.506 | 89.99 | 0.199 | 0.180 | 0.820 | Shale/HC |
| 5182 | 11.77 | 2.250 | 2.146 | 91.08 | 0.197 | 0.188 | 0.812 | Shale/HC |
| 5184 | 11.76 | 2.250 | 2.159 | 86.08 | 0.206 | 0.205 | 0.795 | Shale/HC |
| 5186.5 | 11.72 | 2.240 | 2.172 | 87.72 | 0.203 | 0.204 | 0.796 | Shale/HC |
| 5190 | 11.96 | 2.270 | 2.028 | 90.27 | 0.198 | 0.156 | 0.844 | Shale/HC |
| 5192.5 | 11.62 | 2.340 | 2.834 | 74.94 | 0.225 | 0.364 | 0.636 | Shale/HC |
| 5194 | 11.12 | 2.090 | 5.089 | 50.757 | 0.268 | 0.570 | 0.430 | ? |
| 5195.5 | 12.28 | 2.090 | 27.280 | 29.262 | 0.307 | 0.807 | 0.193 | ? |
| 5197.5 | 12.26 | 2.110 | 153.66 | 27.57 | 0.310 | 0.926 | 0.074 | GAS |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5230.5 | 12.54 | 2.160 | 286.52 | 30.95 | 0.304 | 0.963 | 0.037 | GAS |
| 5240.5 | 14.18 | 2.080 | 105.12 | 31.49 | 0.302 | 0.927 | 0.073 | GAS |
| 5247 | 16.98 | 1.900 | 499.66 | 22.32 | 0.319 | 0.964 | 0.036 | GAS |
| 5260.5 | 15.86 | 1.930 | 980.48 | 26.37 | 0.312 | 0.974 | 0.026 | GAS |
| 5263.5 | 11.05 | 2.090 | 1959.6 | 23.29 | 0.318 | 0.983 | 0.017 | GAS |
| 5270 | 10.67 | 2.080 | 2276.8 | 19.37 | 0.324 | 0.986 | 0.014 | GAS |
| 5329.5 | 11.87 | 2.290 | 1.589 | 88.22 | 0.200 | 0.000 | 1.000 | Shale/water |

*Table 3:* Digital Log Extracts of Horizon M10 Well-4

| DEPTH (ft) | SONIC (Δt) | CALP | G.R (API) | SH | POR | SW | BLK.D g/cc | RT (Ωm) | REMARK |
|---|---|---|---|---|---|---|---|---|---|
| 5099 | 136 | 11.6 | 100 | 0.000 | 0.21 | 1.000 | 2.398 | 1.439 | Shale/w |
| 5100 | 130 | 11.0 | 111 | 0.000 | 0.15 | 1.000 | 2.449 | 1.378 | Shale/w |
| 5109.5 | 111 | 10.1 | 42 | 0.000 | 0.26 | 1.000 | 2.149 | 1.628 | Shale/w |
| 5113 | 119.2 | 9.2 | 38 | 0.658 | 0.24 | 0.342 | 2.132 | 10.56 | Oil |
| 5116.0 | 119.9 | 9.2 | 37 | 0.908 | 0.23 | 0.092 | 2.129 | 49.89 | Oil |
| 5129.5 | 120.8 | 9.2 | 39 | 0.954 | 0.22 | 0.046 | 2.136 | 93.82 | Oil |
| 5130 | 121.2 | 9.0 | 44 | 0.956 | 0.29 | 0.044 | 2.161 | 305.8 | Oil |
| 5162 | 120.9 | 9.0 | 42 | 0.905 | 0.26 | 0.095 | 2.152 | 121.5 | Oil |
| 5166.5 | 120.9 | 9.0 | 42 | 0.855 | 0.25 | 0.145 | 2.152 | 62.88 | Oil |
| 5173 | 124.5 | 9.1 | 44 | 0.922 | 0.23 | 0.078 | 2.161 | 64.80 | Oil |
| 5180 | 124.9 | 9.2 | 48 | 0.987 | 0.24 | 0.013 | 2.177 | 98.6 | Oil |
| 5190 | 124.4 | 9.2 | 47 | 0.897 | 0.25 | 0.013 | 2.174 | 90.8 | Oil |
| 5197 | 121.2 | 9.2 | 49 | 0.907 | 0.24 | 0.093 | 2.197 | 77.11 | Oil |
| 5227.5 | 115.7 | 9.2 | 57 | 0.673 | 0.21 | 0.327 | 2.216 | 9.73 | H.C silt |
| 5390 | 115.7 | 9.5 | 87 | 0.694 | 0.15 | 0.306 | 2.345 | 9.77 | H.C silt |

*Table 4:* Extract of Check Shot Data

| WELL 21 | | WELL 7 | | WELL 4 | |
|---|---|---|---|---|---|
| Sub data Depth(ft) | Seismic Time(ms) | Sub data Depth(ft) | Seismic Time(ms) | Sub data Depth(ft) | Seismic Time(ms) |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5799.8 | 1613.7 | 5680.6 | 1566.9 | 5619.8 | 1544.1 |
| 6641.6 | 1813.3 | 6481.0 | 1741.6 | 6441.7 | 1731.1 |
| 7203.6 | 1931.7 | 7082.9 | 1872.4 | 7066.3 | 1863.0 |
| 7729.6 | 2043.9 | 1614.8 | 1982.9 | - | - |

## IV. DISCUSSION

The digital well log interpretation was done with reference to lithologic and fluid interpretation models proposed and explained in Rider (1986), Schlumberger (1972 and 1974), Dresser Atlas (1982) and Sheriff (1995). Extracts of the

interpretation parameters and their indices as applied in the present study are as shown below:

Density:

Less than 2.150 (g/cc) → Gas
Greater than 2.200 (g/cc) → Water/Shale
Greater than 2.150 (g/cc) but less than 2.200 (g/cc) → Oil

NB g/cc is read grams per centimeter cube

Resistivity:
Less than 5Ωm → Water/Shale
Greater than 5 Ωm to 100 Ωm → Oil
Greater than 100 Ωm → Gas
Gamma ray:
Greater than 60 API → Shale
Greater than 20 but less than 60 API → Sandstone (Rider, 1986; p. 57)
NB. The percentage of shale gradually increases towards and above 60 API

*Table 5:* Interpretation Model for Lithology/Reservoir Fluids Based on Density and Seismic velocity (Sherrif, 1995)

| Lithology | Density | Velocity |
|---|---|---|
| shale | 2.13g/cc | 2287m/s |
| Water sand | 2.08g/cc | 2073m/s |
| Gas sand | 1.98g/cc | 1677m/s |
| Silty sand | 2.11g/cc | 2915m/s |

The time-depth curves for the two reference wells are shown in figures (1 and 2), while equations (1 and 3) are their respective time-depth functions. The calculated depths show that horizon M10 top, in the vicinity of well-7, occurs at 5230 ft and bottomed at 5327 ft, where its thickness was estimated at 97 ft. In well-4, the horizon top was estimated at 5108 ft and its bottom found to be 5194 ft from which the thickness was obtained as 86 ft. On the other hand, Tables (2 and 3) show extracts of digitized wire line log recordings for Wells 7 and 4 respectively, and the depth information contained in column one. The intention was to compare seismic time-depth derived estimates with the depth recordings of the real-time wire-line logs. A comparison of the two results showed that our time-depth conversions fell well within the limits of the reservoir as delineated by the wire-line logs. For instance, the wire-line log interpretation revealed the top of Horizon M10 to occur at 5174.5 ft, and the bottom at 5329.5 ft, while the seismic time-depth conversion gave 5230 ft and 5327 ft respectively. In Well-4, the wire-line recordings were; 5099 ft for the top of M10 and 5390 ft for its bottom while the time-depth conversion for this particular Well (4) were; 5108 ft for the top and 5194 ft for its bottom as earlier noted. The lithology and fluid interpretations based on combined well-log parameter analysis using templates highlighted in the beginning of this section showed that horizon M10 has a top and bottom shale seal housing the sandstone reservoir in both wells (tables 1 and 2). It could be recalled that shale is basically radioactive, accounting for why its presence has been associated with larger API values which were used to delineate the lithology. Also, a gas filled porosity exhibits higher resistivity than an oil filled porosity, the same is true for sonic velocity and the density parameters in a logging environment, even as shale tends to be denser than sandstone (Rider, 1986).

## V. CONCLUSION

It could be seen that the depth estimates derived from the seismic time-depth conversions fell within the reservoir limits but not without some level of error which lead to underestimation of the reservoir thickness as observed in the bottom tie of well-4. Since the estimated depth and thicknesses are within the range of actual values as revealed by the wire-line logs, the time-depth conversion is thus to a fare approximation reliable, hence could be used in this X-field where integral and/or statistical analysis of the check shots velocity with other sources of velocity information is suggested for enhanced results and better accuracy. Aided by information on hydrocarbon saturation in the $7^{th}$ and $5^{th}$ columns of tables 2 and 3 respectively; horizon M10 in the vicinity of well-7 was interpreted to be composed majorly of gas sands while well-4 has reservoir sands with oil filled porosity.

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# The First Study on Nuclear Polyhedrosis Virus Histopathological and Morphological Effects on the Strawberry Pest, *Pentodon Algerinum* (coleoptera: Scarabaeidae)

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## ABSTRACT

In Egypt, strawberry is an economically important crop that has recently been destroyed by Pentodon algerinum, a worldwide polyphagous destructive insect pest. This study aimed to distinguish, for the first time, the histopathological and morphological effects of Spodoptera littoralis Nuclear polyhedrosis virus (SpliNPV) and Pentodon algerinum Nuclear polyhedrosis virus (PNPV) on Pentodon algerinum third instar larvae to confirm their success as safe alternative control agents against this pest. The results showed that PNPV and SpliNPV affected Pentodon larvae by the same effects in causing the following: integument deformation and rupture; the destruction of the hypodermal layer resulting in the inhibition of the process of molting into the pupa stage, reducing pest survival; larva leg corrosion, which prevents its spreading; the rupture of fat bodies, which leads to the loss of stored energetic materials; the distortion of muscle sarcolemma and fibers resulting in weakness and softness; the tracheal cuticular layer destruction, which inhibits breathing; midgut rupture with cells detaching from each other; irregular cytoplasm distribution; the loss of the columnar shape of cells; the appearance of vacuoles between cells, which results in their inability to feed or to digest; the swelling, softness, liquefaction, and, lastly, death of the larva.

*Keywords:* pentodon algerinum, nuclear polyhedrosis virus, pnpv, splinpv, histopathology, morphology.

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*Language:* English

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## ABSTRACT

*In Egypt, strawberry is an economically important crop that has recently been destroyed by Pentodon algerinum, a worldwide polyphagous destructive insect pest. This study aimed to distinguish, for the first time, the histopathological and morphological effects of Spodoptera littoralis Nuclear polyhedrosis virus (SpliNPV) and Pentodon algerinum Nuclear polyhedrosis virus (PNPV) on Pentodon algerinum third instar larvae to confirm their success as safe alternative control agents against this pest. The results showed that PNPV and SpliNPV affected Pentodon larvae by the same effects in causing the following: integument deformation and rupture; the destruction of the hypodermal layer resulting in the inhibition of the process of molting into the pupa stage, reducing pest survival; larva leg corrosion, which prevents its spreading; the rupture of fat bodies, which leads to the loss of stored energetic materials; the distortion of muscle sarcolemma and fibers resulting in weakness and softness; the tracheal cuticular layer destruction, which inhibits breathing; midgut rupture with cells detaching from each other; irregular cytoplasm distribution; the loss of the columnar shape of cells; the appearance of vacuoles between cells, which results in their inability to feed or to digest; the swelling, softness, liquefaction, and, lastly, death of the larva. Thus, PNPV and SpliNPV were effective against the Pentodon larva and caused various physiological changes that disrupted its normal functions, leading to the collapse of its population. Hence, PNPV and SpliNPV can be recommended as eco-friendly safe alternative biological control agents against Pentodon algerinum.*

*Keywords:* *pentodon algerinum,* nuclear polyhedrosis virus, *pnpv, splinpv*, histopathology, morphology.

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## I. INTRODUCTION

The strawberry (*Fragaria ananassa*) is of high nutritional value and great economic importance. (Francesca et al., 2012). In 2014, Egypt ranked 4$^{th}$ globally in the quantity and quality of strawberry production. (FAO, 2016). Furthermore, in 2016–2019, Egypt ranked 6$^{th}$ among the top 10 producers of strawberries worldwide (FAOSTAT, 2021).

*Pentodon algerinum* is a ubiquitous agricultural polyphagous insect pest that has recently been destroying strawberry in Egypt. *Pentodon* larvae are known as the waste organic manure larvae (White grubs).The larva has a brown head and a thick large arched yellowish body (Abd El-Salam, 2019; Ramadan and Mahmoud, 2021). The larvae live in sandy soil around the roots of plants in a curved shape, forming the letter "C," and feed on organic matter and plant roots or tubers, causing the plant to wilt and die rapidly (Abd El-Salam 2019; Samah et al., 2021).

The use of chemical pesticides causes health problems to humans, toxicity to domestic animals

and beneficial insects, also causes resistant insect development to traditional pesticides and increases environmental pollution (Abd El-Salam et al., 2013; Parra, 2014). As such, there is a strong need to find alternative pesticides for insect pest control such as entomopathogenic baculoviruses (Samah et al., 2019, 2021).

The development of baculoviruses (including nuclear polyhedrosis virus) as biological insecticides is required for maintaining food safety and ecological security (Zhao et al., 2019; Abid et al., 2020a, 2020b; Qayyum et al., 2020; Wilson et al., 2020; Yasin et al., 2020).

Baculovirus cannot infect humans because it needs an alkaline-based cell structure to replicate itself, whereas the human cell structure is acidic-based. Also, it requires complementing with its specific receptor sequence on the insect target cell surface for its entry to initiate infection. This receptor is not found in humans. Virus receptor complementing is too specific on both the species and the cell type infected by a given virus. Therefore, baculoviruses are safe alternative biological insect pest control agents such as Nuclear Polyhedrosis Virus (NPV) by virtue of their having double-stranded DNA and being highly specific to their host insects (Salama et al., 2017; Samah et al., 2019, 2021; Masson et al., 2021).

Baculoviruses block molting and interfere with normal development, causing a weak expression of the ecdysteroid UDP (Uridine diphosphate) glucosyltransferase gene that encodes the ecdysteroid UDP–glucosyltransferase enzyme, which induces the transfer of glucose from UDP-glucose to ecdysteroids, insect molting hormones (O´Reilly, 1995).

Studies on the histopathological effect of the *Zetheniaru fescentaria Nuclear Polyhedrosis Virus (ZrNPV)* on the *Zetheniaru fescentaria* Motsch larvae have confirmed that *ZrNPV* multiplies within the nuclei of epidermal cells, fat bodies, blood cells, the tracheal matrix, and midgut cells, destroying them in the process (Daibin et al., 1999).

Histopathological studies on the effects of the *Diaphania pulverulentalis Nuclear Polyhedrosis Virus* (*DpNPV*) on *Dp* larvae have revealed that the midgut infected by *NPV* was characterized by hypertrophy of virions-filled nuclei and, therefore, the death of leaf Webber larvae (Pachiappan et al., 2018).

This study aimed to distinguish, for the first time, the histopathological and morphological effects of *Spodoptera littoralis Nuclear polyhedrosis virus* (*SpliNPV)* and *Pentodon algerinum Nuclear polyhedrosis virus* (*PNPV*) on *Pentodon algerinum* third instar larvae to confirm their efficacy as eco-friendly safe alternative biological control agents against *Pentodon algerinum*.

## II. MATERIALS AND METHODS

### *2.1 Production and isolation of Nuclear Polyhedrosis virus*

The original Nuclear Polyhedrosis virus (NPV) types were produced and isolated from infected *Spodoptera littoralis* larvae as *SpliNPV* and from infected *Pentodon algerinum* larvae as *PNPV* by Samah M.M. Abd EL-Aziz (Salama et al., 2017; Samah et al., 2019, 2021) at the laboratory of Pests & Plant Protection Department, National Research Centre, Egypt, and stored at -20°C till use.

### *2.2 The Histopathological and Morphological investigations of the effects of PNPV and Spli NPV on the Strawberry pest, Pentodon algerinum*

Third instar larvae infected by *PNPV* and *SpliNPV* were investigated histopathologically and morphologically until death.

#### *2.2.1 The histopathological investigation was made according to (Prophet et al., 1992) as follows*

Tissue processing, which entails dehydration, clearing, and infiltration, took 3–4hours.

The sample was rinsed briefly in running water, with the passage of the sample through ethyl alcohol (80%) if necessary, followed by its passage through Ethyl alcohol (95%) for three time changes (15–20minutes per time change),

followed by its passage through pure ethyl alcohol for 15minutes, through equal portions of absolute ethyl alcohol and xylene for 15minutes, through Xylene for two time changes (15minutes per time change), through paraffin for three time changes (15minutes per time change), through paraffin in a vacuum for 15–20minutes, and then embedding.

The fixation by Harris' hematoxylin and Eosin procedures took a maximum of three hours:

Fixation: In Bouin's or Zenker's solution (10% buffered neutral formalin).

Sections: Paraffin, frozen or celloidin, 3–20micrometers.

Solutions: Acid alcohol (1%), Ammonia water, saturated Lithium carbonate, Eosin-Phloxine solution, Harris' hematoxylin (5g of hematoxylin, 50ml of ethyl alcohol (100%), 100g of potassium or ammonium, alum, 1000ml distilled water, and 2.5g of mercuric oxide, red).

Slides are Deparafinized and dehydrated to distilled water with Dezenkerizing (if necessary) before staining, followed by staining in freshly filtered Harris' hematoxylin for 6–15 minutes, then Washing in running tap water for 2–15minutes, differentiating in acid alcohol (1%) with 1–2dips, then washing briefly in tap water, placing in weak ammonia water or saturated lithium carbonate solution until the sections are bright blue, washing thoroughly in running tap water for 10minutes, placing in ethyl alcohol (80%) for 1–2minutes, counterstaining in Eosin-Phloxine solution for 2minutes, dehydrating and clearing through two changes, each of ethyl alcohol (95%), absolute ethyl alcohol, and xylene (2minutes each), and then mounting with resinous media.

The slides were investigated and photographed under a light microscope.

### *2.2.2 Morphological investigation*

Morphological investigation was carried out by recording and photographing any malformation noticed after infection till death.

## III. RESULTS

This study revealed that *PNPV* and *SpliNPV had* the same histopathological and morphological effects on this pest larva.

### *3.1. Histopathology of NPV- infected Pentodon larva integument.*

The infected larva integument appeared filled with NPV viral particles. Also, it was deformed and ruptured compared with the healthy larva, leading to leg corrosion as morphological malformation (Figs. 12a, b, c, d, e, f) compared to the normal larva (Figs. 11a, b), preventing this pest from spreading. The destruction of the hypodermal layer was also observed. Furthermore, the irregular shape of the cuticular layer and its detachment from the underlying hypodermal layer was recorded (Figs. 2a, b, c, d, e) compared with normal integument (Figs. 1a, b, c)**.** The destruction of the hypodermal layer led to the inhibition of the process of molting to the pupa stage; therefore, the rate of survival of this pest was reduced. On the other hand, normal *P. algerinum* larvae molted to the pupa stage, then to the adult stage (Figs. 11c, d).

### *3.2 Histopathology of NPV-infected fat bodies*

The infected larva fat bodies lost both adipocytes & fusion of lobules, leading to the collapse of the lobular architecture. They lost waste granules and they were filled with viral particles. Also, there was shrinkage of the fat bodies with vacuoles between cells with unclear nuclei and rupture of the cell sheath (Figs. 4a, b, c, d, e, f, g) compared with normal fat bodies (Figs. 3a, b, c, d, e); therefore, energy reserves were lost, leading to the dryness of the infected larva as a morphological symptom (Fig. 12g, h, i) compared to the normal larva (Figs. 11a, b).

### *3.3 Histopathology of NPV-infected larval muscles.*

The infected larval muscles were filled with NPV and appeared with irregular shapes of sarcolemma with fissure-like appearances. The fibers were also distorted and not compacted (Figs. 6a, b, c, d, e) compared with normal muscles (Figs. 5a, b). Thus, weakness and softness

were the resulting morphological symptoms (Fig. 12a, b, c, d, e, f, g, h, i) in the infected larvae compared to normal larvae (Figs. 11a, b).

### *3.4 Histopathology of the NPV-infected Pentodon larva's tracheal matrix*

The infected larva's tracheal matrix was filled with Nuclear Polyhedrosis virus, also had a crushed cuticle layer and acute necrosis around it (Figs. 8a, b, c, d) compared with the normal tracheal matrix (Figs. 7a, b). Therefore, the inability to breathe occurred as a result.

### *3.5 Histopathology of the NPV-infected Pentodon larva's gut region*

The infected larva's gut region was filled with viral particles and appeared with no distinguishing of any cells. Also, the midgut was destroyed with the detachment of cells from each other, the irregular distribution of the cytoplasm, cells losing of their columnar shape, and the appearance of vacuoles between cells (Figs. 10a, b, c, d) compared with the normal midgut (Figs. 9a, b, c). All these caused the inability of NPV-infected larva to feed or to digest, which leads to swelling, softness, and liquefaction as morphological effects caused by the virus (Figs. 12j) compared to the normal larvae (Figs. 11a, b). All these culminate in the death of the infected larvae.

### *3.6. Morphological investigation*

Morphological investigation revealed that *PNPV* and *SpliNPV* infection had the same signs and symptoms, including corrosion of the legs of the larva, which decreases its spreading and causes dryness, weakness, swelling, softness, liquefaction, bursting, and, finally, the death of these larvae. Also, the process of molting to the pupa stage was inhibited, leading to the interruption of the life cycle of this pest, which represents impairment in the survival of the species. A comparison of the interrupted life cycle to the normal life cycle of the larva is seen in (Figs. 12a, b, c, d, e, f, g, h, i, j) vs. (Figs. 11a, b, c, d).

## IV. DISCUSSION

All these findings are in line with those of the following studies:

Baculovirus inhibits the process of molting and causes the weak expression of the ecdysteroid UDP (Uridine diphosphate) glucosyltransferase gene that encodes the ecdysteroid UDP–glucosyltransferase enzyme that induces the transfer of UDP-glucose to ecdysteroids, the insect molting hormone (O´Reilly,1995).

The histological investigation of *Zethenia rufescentaria* Motsch larvae after infection by *ZrNPV* under optical and electron microscopes indicated that *ZrNPV* destroyed fat bodies, epidermis cells, tracheal matrix, midgut cells, and, blood cells. These cells indicate major cytopathic effects, and their nuclei were fulfilled with NPV viral particles and were swollen (Daibin et al., 1999).

The midgut epithelial cells of *Diaphania pulverulentalis* Nuclear Polyhedrosis Virus (*DpNPV*)-infected larvae had irregularly shaped hypertrophied nuclei filled with large numbers of polyhedral bodies compared to normal nuclei. (Deng et al., 1991; Yan et al., 1991; Yu et al., 1993; Sanjaya et al., 2010). *ZrNPV* had a strong efficacy indoors and in the field in rapidly causing viral epidemic disease among insect hosts in a large area of the forest (Daibin et al., 1999). *ZrNPV* could also infect the muscular sheath, nerve sheath, and pericardial cells (Huang 1987; Zhang 1988).

The histological and ultrastructure investigations of the Nuclear Polyhedrosis Virus- infected webbing clothes moth (*Tineolabis selliella*) under the electron microscope showed that NPV Polyhedra replicated in the nuclei of the cells of the foregut, midgut, hindgut, cardiac valve, pyloric valve, Malpighian tubules, muscle, ganglia of the ventral nerve cord, fat bodies, tracheae, and hypodermis. Also, virions are transported from the gut lumen in vesicles through the cytoplasm into the nuclei of columnar cells, and then they take a part of the membrane to be occluded in a polyhedral protein (Hunter et al., 1973).

The histopathology of the Nuclear Polyhedrosis Virus-infected Almond Moth (*Cadra cautella*) indicated that NPV replication was primarily and mainly in the nuclei of the hypodermis, fat body, tracheal matrix, blood cells, Malpighian tubules, the epithelial & connective tissues, the nervous system, the reproductive organs, muscles, and the frontal midgut cells that secret the peritrophic membrane (Jean et al., 1968).

Histopathological studies of the *Diaphania pulverulentalis* Nuclear Polyhedrosis Virus (*DpNPV*)-infected larvae revealed more infection with *NPV* in the midgut, which was distinguished by the hypertrophy of nuclei filled with virions causing the death of leaf Webber larvae. Due to *DpNPV*- restricted host specificity and non-toxicity to beneficial insects, it could be used as a safe biopesticide for the management of leaf Webber in the mulberry ecosystem (Pachiappan et al., 2018).

While there are few studies by other authors on the virus experimenting on coleopteran insects such as (Alois, 2005) who studied the effect of the *Oryctes* virus on *Oryctes rhinoceros* (Coleoptera: Scarabaeidae). This isolated virus was the first non-occluded, rod-shaped insect virus that resembled the baculoviruses morphologically. He studied the virulence and histopathology of this virus, confirming that it was infectious to larvae by oral application; therefore, massive disintegration and vacuoles of fat body tissue of a virus-infected third instar larva were observed.

Insects that are killed by baculoviruses are shiny-oily colored and crawl to the plant top where they die and decompose. The infected larvae are liquefied and rupture, releasing infective viral particles (Ramanujam et al., 2014; Devi et al., 2016). Also, there are many distinguishing symptoms such as sluggishness, skin discoloration, regurgitation of fluids, wet droppings, and larvae hanging upside down in the top of the plant, which is known as tree top disease (Sharma and Srivastava, 2013; Devi et al., 2016). Other insects can be infected by eating contaminated foliage with virus-ruptured larvae (Ramanujam et al., 2014).

## V. CONCLUSION

Strawberry is an economically important plant in Egypt. The white grub, *Pentodon algerinum* (Coleoptera: Scarabaeidae) is a dangerous worldwide pest of several important plants (recently including strawberry in Egypt) and has caused massive destruction of the crop. This study aimed to distinguish, for the first time, the histopathological and morphological effects of *Spodoptera littoralis Nuclear polyhedrosis virus* (*SpliNPV)* and *Pentodon algerinum Nuclear polyhedrosis virus* (*PNPV*) on *Pentodon algerinum* third instar larvae to confirm their success as eco-friendly safe alternative biological control agents against *Pentodon algerinum*. The results confirmed that *PNPV* and *SpliNPV* were effective against the *Pentodon* larva and caused various physiological changes disrupting its normal functions, leading to the collapse of its population. *PNPV* and *SpliNPV* are not harmful to humans and other animals and are also host-specific; therefore, they can be recommended as eco-friendly safe alternative biological control agents against *Pentodon algerinum*.

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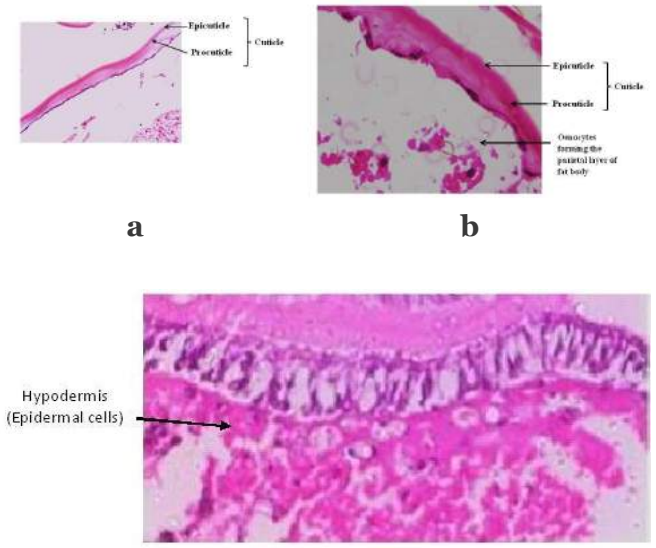
Figure legends

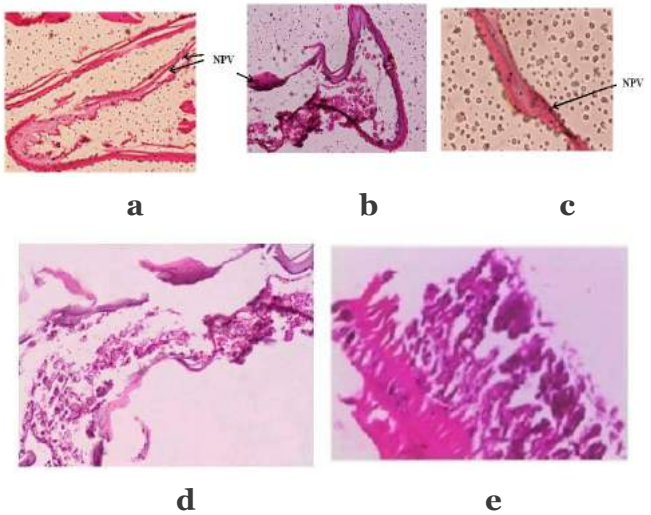
Figure 1 The histology of normal integument of *P. algerinum* larva




*Figs. 1a, b, c:* Longitudinal section of normal *P. algerinum* larvae showing a normal complete integument structure and a normal hypodermal layer (Magnification = 200, 400×)

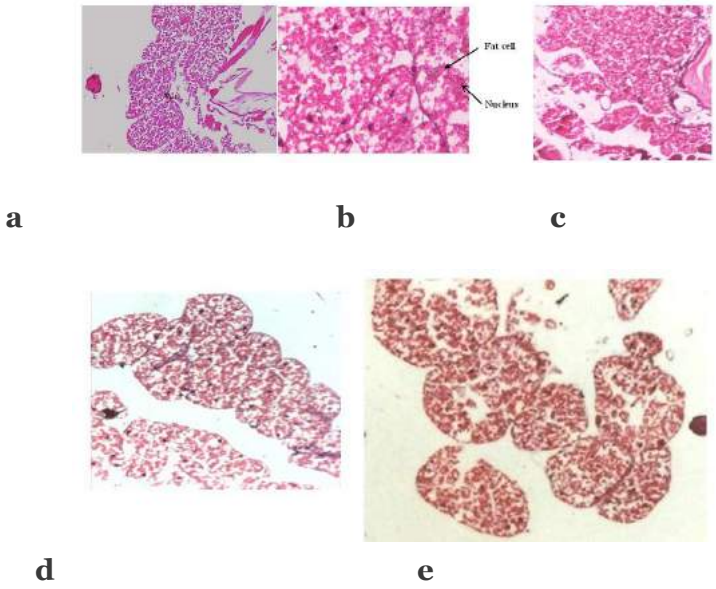
The normal integument is considered as a protective body covering, a surface for muscle attachment, a water-tight barrier against desiccation, and a sensory interface with the environment. It is a multi-layered structure with 3 important layers: The cuticle (consisting of an epicuticle (Cement, wax, polyphenol and, Cuticulin layers) & procuticle (Exocuticle and Endocuticle)), hypodermis, and basement membrane.

Figure 2 The histopathology of the NPV-infected *P. algerinum* larval integument after infection




*Figs. 2a, b, c, d, e:* Longitudinal section of the NPV-infected integument of the *Pentodon* larva showing NPV particles and the discontinuity of the cuticle layer with undistinguished hypodermal cells (Magnification = 200×).

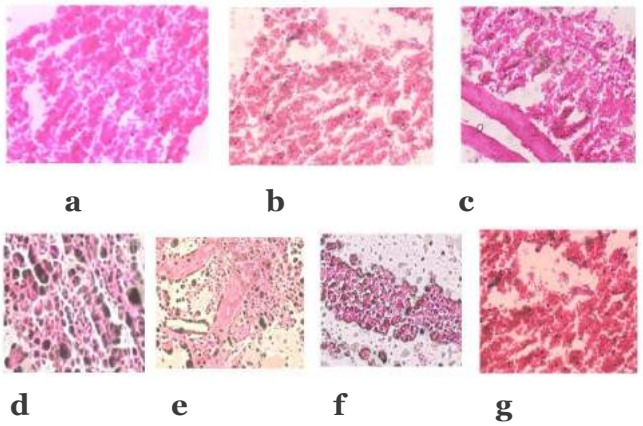
Figure 3 The histology of normal fat bodies of *P. algerinum* larvae




*Figs. 3a, b, c, d, e:* Longitudinal section of the normal *P. algerinum* larva showing normal fat bodies (Magnification = (200,400×)

The normal fat body consists of hexagonal contacted fat cells filled with storage materials. It has complete cells with a completed structure, nucleus, and complete cell sheath. The fat body is the tissue that occupies the spaces between the insect's organs. It is composed of cells of mesodermal origin and sometimes also contains ectodermic cells. It is identified as the perivascular layer, which is located around the organs, and the parietal layer, which is located adjacent to the integument. It is responsible for the storage of lipids, carbohydrates, and proteins, and for the synthesis of vitellogenins that are important for the insect's reproduction through their incorporation into the oocytes during vitellogenesis.

Figure 4 The histopathology of fat bodies of the Nuclear Polyhedrosis virus (NPV)-infected *P. algerinum* larva




*Figs. 4a, b, c, d, e, f, g:* Longitudinal section of NPV-infected *Pentodon* larva fat bodies

NPV-infected fat bodies lose both adipocytes and the fusion of lobules. The lobular architecture collapsed. They were filled with viral particles and had no waste granules. Also, there was the shrinkage of the fat bodies with vacuoles between cells with unclear nuclei and the rupture of the cell sheath. Hence, energy reserves were lost. (Magnification = 200, 400×).

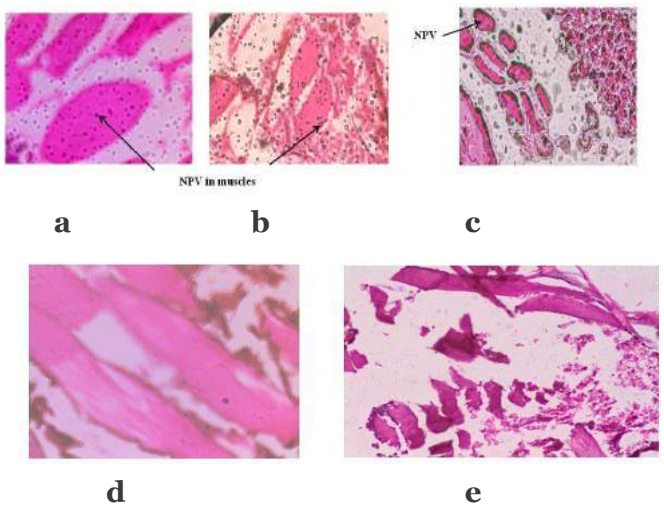
Figure 5 The histology of the normal muscular system of the *Pentodon* larva


**a** **b**

*Figs. 5a, b:* Longitudinal section of a normal *P. algerinum* larva showing normal muscles (Magnification = 400×)

Normal muscle consists of many long fibers being compacted and surrounded by the sarcolemma membrane. A muscle fiber is composed of many fibrils, which gives the cell its striated form. Each fibril is subdivided into separate, smaller fibrils formed from a greatly organized array of myofilaments made up of actin & myosin and alternating isotropic and anisotropic regions looking like light and dark bands or disks under the microscope.

Figure 6 The histopathology of muscles of the *NPV-infected P. algerinum* larva



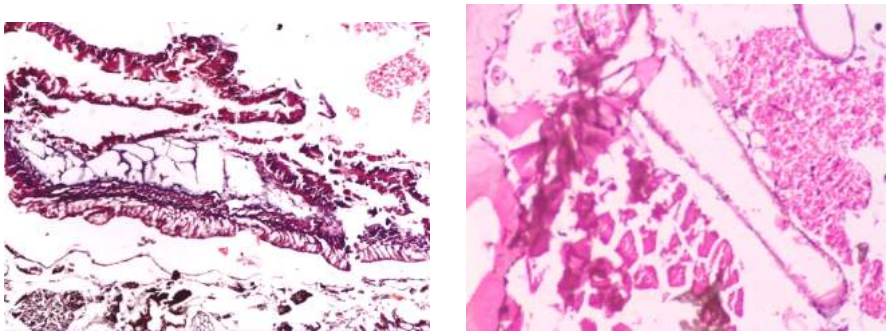

**a** **b** **c**

**d** **e**

*Figs. 6a, b, c, d, e:* Longitudinal section of the NPV-infected *Pentodon* larva muscles (Magnification = 200, 400×)

NPV-infected larval muscles were filled with NPV and appeared with irregular shapes of the sarcolemma with a fissured appearance; also, the fibers are distorted and not compacted.

Figure 7 The histology of the normal tracheal matrix of the *P. algerinum* larva

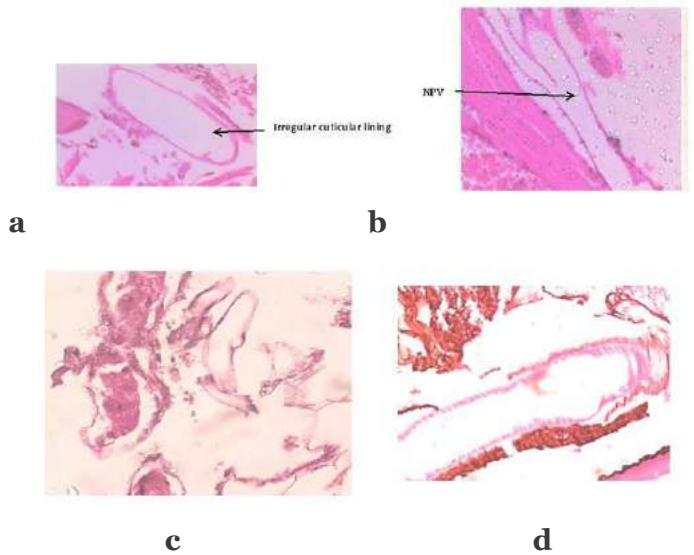


**a** **b**

*Figs. 7a, b:* Longitudinal section of the normal *P. algerinum* larva's trachea (tracheal matrix) (Magnification = 200,400×).

The tracheal system is responsible for transporting sufficient oxygen ($O_2$) to all body cells and for removing carbon dioxide ($CO_2$) produced as a waste product of cellular respiration. Histologically, the trachea (tracheal matrix) comprises a cuticle layer, the epidermis, and a basement membrane, all of which are directly continuous with similar layers forming the general body wall. All or most of the cuticular lining of the trachea-spiracle system is usually shed during ecdysis. The *P. algerinum* larva has a peripneustic respiratory system with spiracles in a row along each side of the body.

Figure 8 The histopathology of the NPV-infected tracheal matrix of the *P. algerinum larva*.



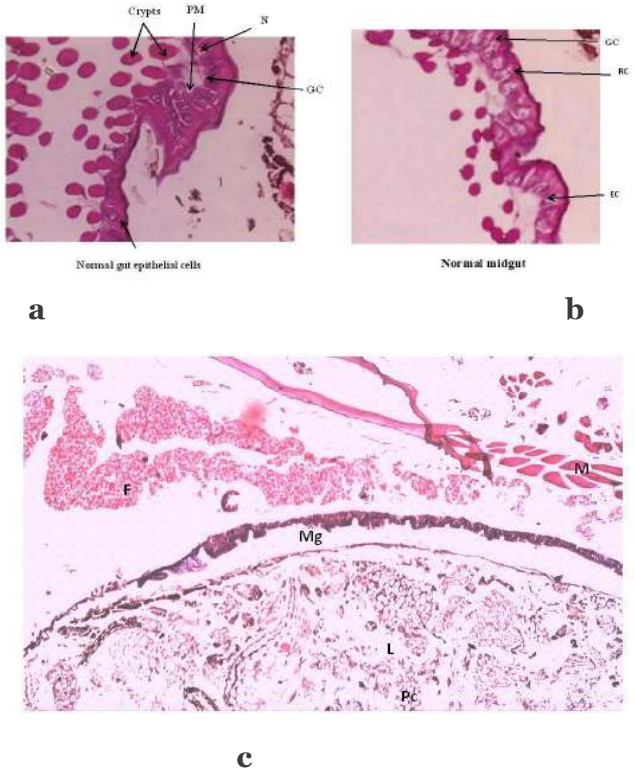

**a** **b**

**c** **d**

*Figs. 8a, b, c, d:* Longitudinal section of the NPV-infected *Pentodon* larva's tracheal matrix with a crushed cuticular layer surrounded by acute necrosis. (Magnification = 200, 400×)

There was the destruction of the cuticular layer of the trachea filled with the Nuclear Polyhedrosis virus (NPV).

Figure 9 The histology of the normal midgut of the *P. algerinum* larva

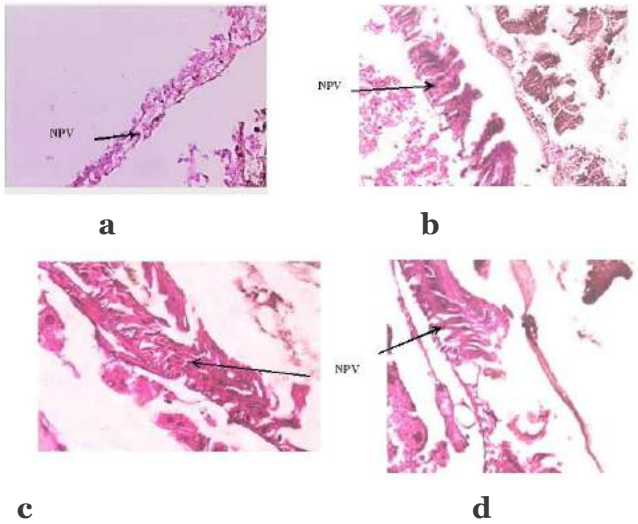



*Figs. 9a, b:* Longitudinal section in the normal *Pentodon* larva (Magnification = 400×) showing the normal midgut region. GC = goblet cells, N = Nucleus, PM = Peritrophic membrane, Rc = Regenerative cells, EC = Epithelial cells

Fig. 9c: Transverse section of the normal *Pentodon* larva showing: F = fat bodies, M = Muscles, Mg = Midgut, L = Lumen of the midgut filled with (Pc = plant cells food) (Magnification = 100×).

The normal midgut appeared with the complete shape. The normal epithelial cells appeared with a homogenous cytoplasm and a basic nucleus. The cells are attached and folded to form crypts. Goblet cells (Gc) and regenerative cells (Rc) were also observed.

Figure 10 The histopathology of the NPV-infected *P. algerinum* larval midgut



Figs10a, b, c, d: Longitudinal section of the NPV-infected *Pentodon* larva (Magnification = 200×) show the NPV-infected destroyed midgut of the *Pentodon* larva and no distinguishing of any cells in the NPV-infected gut region, a detachment of cells from each other, unformed distribution of the cytoplasm, cells losing their columnar shape, and the appearance of vacuoles between cells. (Magnification = 200×).

Figure 11 The morphological investigation figures Normal *Pentodon algerinum* stages

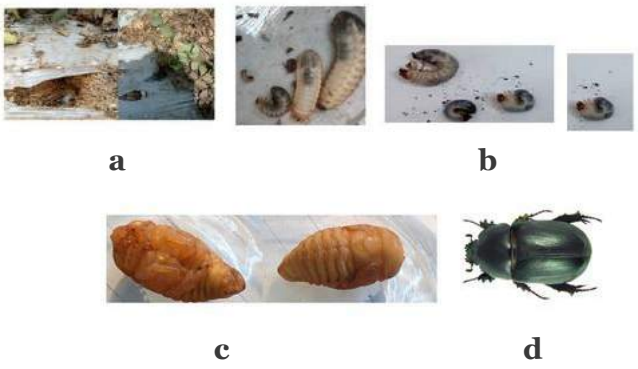
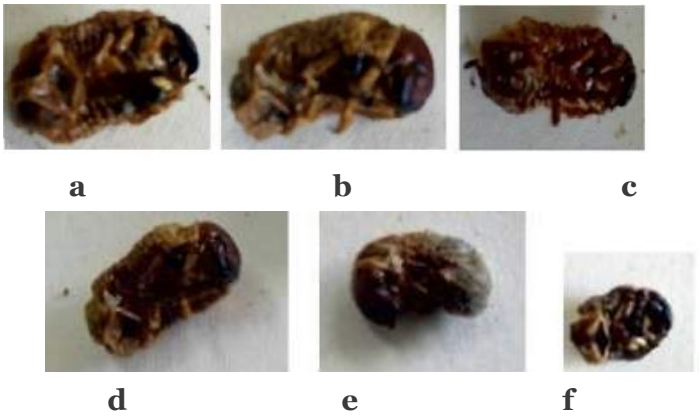



*Fig. 11 a:* Normal *P. algerinum* larvae under the plant root, Fig. 11b: Normal *Pentodon* larval instars

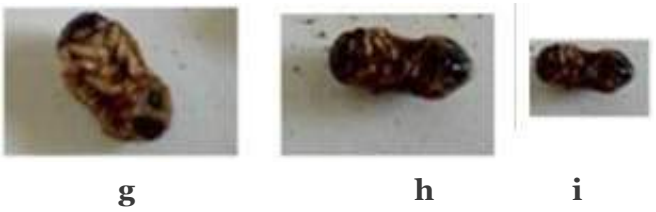
*Fig. 11c:* Normal *Pentodon* pupa, Fig. 11d: Normal *Pentodon* adult

*Figs. 11a, b, c, d:* Normal *Pentodon algerinum* stages

Figure 12 The morphological Symptoms of *PNPV* and *SpliNPV-infected* dead *P. algerinum* larvae




Dryness, weakness, leg corrosion, and death




Dryness, weakness, and death

**j**

*Figs. 12a, b, c, d, e, f, g, h, i, j:* Morphological symptoms of *PNPV* and *SpliNPV-infected* dead *P. algerinum* larvae

These images show that *PNPV* and *SpliNPV* caused the same symptoms in the larvae, including the corrosion of the larva legs, which decreases its spreading and, also caused dryness, weakness, swelling, softness, liquefaction, bursting, and, finally, the death of these larvae. Also, the process of molting to the pupa stage was inhibited, leading to an interruption of the life cycle of this pest, which results in pest survival reduction.