OPERATIONAL FACTORS AFFECTING MATURITY OF UNITS IN THE BEYPAZARI TRONA MINE

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ABSTRACT

OPERATIONAL FACTORS AFFECTING MATURITY OF UNITS IN THE BEYPAZARI TRONA MINE

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Solution mining method is used for extracting trona ore from underground at the Beypazarı trona mine. Two vertical and one directionally drilled well are combined in a target trona seam as a production unit. Solvent containing 2-3 % Total Alkalinity at a temperature between 60-80 ^{o}C is injected from horizontal well and brine is taken from vertical wells with 14-15 % Total Alkalinity (TA) with a temperature of 40-50 ^{o}C. When brine concentration of units reaches design parameters, production unit is called as mature unit.

There are some operational factors affecting the maturity of production unit. In this thesis, injection temperature and injection flow rate is observed as operational factors of production units depending on time. To see how operational factors, affect the increase of ing brine concentration, 19 units were chosen from Beypazarı study area. At first, a regression analysis is done for the units, separately and then test is done for U6 trona seam to estimate maturity time of units with the help of operational and external factors.

According to result of regression analysis, 10 of 19 units could be explained by the effect of injection temperature and flow rate depending on time with R^2 (adj) is 56.8 % and it is estimated that units drilled in U6 trona seam can reach maturity level between 2,000-3,000 hours with 32 % R^2 (adj) value.

Keywords: Trona, Solution Mining, Injection Temperature, Solvent Flow Rate, Maturity

ÖZ

BEYPAZARI TRONA MADENİNDE ÜRETİM ÜNİTELERİNİN OLGUNLAŞMA SÜRESİNİ ETKİLEYEN OPERASYON FAKTÖRLERİ

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Beypazarı trona madeninde, tronanın çıkarılması için çözelti madenciliği metodu kullanılmaktadır. İki dik ve bir yönlü üretim kuyuları hedeflenen trona damarında birleştirilerek üretim üniteleri oluşturulmaktadır. % 2-3 toplam alkaliniteli 60-80 ºC sıcaklığında çözücü yatay kuyudan enjekte edilir ve % 14-15 toplam alkaliniteli (TA) 40-50 ºC sıcaklığındaki çözelti dik kuyulardan çekilir. Üniteler bu dizayn parametrelerine ulaştığında, olgunlaşmış ünite olarak adlandırılırlar.

Ünitelerin olgunlaşmasını etkileyen birtakım operasyonel faktörler vardır. Bu tezde, enjeksiyon sıcaklığı ve enjeksiyon debisi operasyonel faktörler olarak zamana bağlı incelenmiştir. Operasyonel faktörlerin çözelti konsantrasyon artışına etkisini görmek için Beypazarı çalışma sahasından 19 ünite seçilmiştir. Öncelikle, üretim üniteleri için ayrı ayrı regresyon analizi yapılmıştır. Sonrasında, U6 trona damarı için aynı test kullanılarak operasyonel ve dış faktörler yardımı ile bu damarda delinen ünitelerin olgunluk zamanları tahmin edilmeye çalışılmıştır.

Elde edilen regresyon sonuçlarına göre, seçilen 19 üniteden 10 tanesinde enjeksiyon sıcaklığı ve debisi zamana bağlı olarak % 56.8 düzeltilmiş R2 ile açıklanmıştır. U6 trona damarında delinen üretim kuyuları ise % 32 R2 ile açıklanmış olup 2.000-3.000 saat aralığında olgunluk seviyesine eriştiği görülmüştür.

Anahtar Kelimeler: Trona, Çözelti Madenciliği, Enjeksiyon Sıcaklığı, Enjeksiyon Debisi, Olgunluk

To My Precious

For his everlasting support and encouragement

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TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1. General

Trona is one of the evaporate mineral (Figure 1). It is called as trisodium hydrogen dicarbonate dihydrate or sodium sesquicarbonate dehydrate. Chemical formula of trona is $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$. Its density is 2.17 g/cm^3 and this mineral is easily soluble in water, non-flammable and non-harmful.

Figure 1. Trona (http://www.greatmining.com/mining_images/trona1.png)

Trona is extracted from underground as brine containing sodium carbonate and sodium bicarbonate in Beypazarı Trona Field. Soda ash and sodium bicarbonate (baking soda) are products of brine in this area. Brine is used to make soda ash (Na_2CO_3) by heating it to high temperature (95-103 °C) and it also used to make to sodium bicarbonate by cooling brine with carbon dioxide.

There are three production methods of soda ash. They are production from natural soda reserves, lakes and production synthetically by Solvay process (Örgül, 2003). In

Beypazarı study field, soda ash is produced by only natural soda reserves without using rock salt (sodium chloride) and limestone (sodium carbonate) as raw material.

Soda ash is used by the industries such as glass manufacturing, cement production, chemical, pulp and paper, soap and detergent industry. Trona effectively removes acid gases such as oxides of sulfur (SO_2 and SO_3), hydrochloric acid (HCl), and hydrofluoric acid (HF) from flue gas emissions (Great Mining, n.d.).

Sodium bicarbonate is produced in three (3) types in the study area; food, feed and technical. Food type sodium bicarbonate is used at baking powders, cake and cookie additives, beverages and dentifrices. Feed type sodium bicarbonate is used for dairy, poultry and pig farming. Moreover, technical type is used at powder fire extinguisher, flue gas desulphurization, cleaning agents, and leather and textile industry.

The largest trona deposit in the world is located in Green River, Wyoming, United States. It was deposited in a lake during the Paleogene Period. It has 47 billion tons of identified soda ash resources which are in beds more than 1.2 meters' thickness. The mining method of Wyoming trona deposit is room and pillar with 45 % mining recovery. Every year almost 15 million ton trona is extracted from Green River Basin, Wyoming and it means yearly soda ash production is 8.3 million of soda ash. Furthermore, trona is mined Lake Magadi in the Kenyan Rift Valley for nearly 100 years (Bolen, 2017).

Moreover, The Wucheng basin trona mine located at Henan Province in China has 36 trona beds (693–974 m deep), the lower 15 beds are 0.5–1.5 m thick, thickest 2.38 m; the upper 21 beds are 1–3 m thick, with a maximum of 4.56 m hosted and underlain by dolomitic oil shales. Also trona is found at Owens Lake and Searles Lake, California.

According to the report published by U.S. Geological Survey, Mineral Commodity Summaries, in 2018, 15 million tons of soda ash was produced all over the world in 2017 (Table 1).

Table 1. World trona production (Mineral Commodity Summaries 2018, 2018)

Natural Soda Ash	Mine Production (t)		Reserves (t)
	2016	2017	
United States	11,800,000	11,800,000	23,000,000,000
Botswana	250,000	250,000	400,000,000
Kenya	450,000		7,000,000
Turkey	1,900,000	2,100,000	840,000,000
Other countries	-	15,000,000	280,000,000
World total natural production	**14,400,000**	**15,000,000**	**25,000,000**
World total synthetic production	**39,200,000**	**39,000,000**	**-**
World total production	**53,600,000**	**54,000,000**	**-**

In Turkey, Beypazari and Kazan region in the Ankara Province of Turkey have 250 million and 1,650 million tons of trona reserve, respectively. Soda ash production in Turkey has increased to 2.5 million tons per year and over the next few years it will be increased to 4.4 million tons per year.

In 1979, trona was identified in Beypazarı by MTA during coal exploration. After that MTA and other governmental agencies began exploration work targeting and characterizing the trona deposit (Onargan & Helvacı, 2001). Exploration works were continued until 2001 and after this year, production has started with conventional mining method in the field.

According to geological and hydrological conditions, and cost issues, these parties agreed that long wall underground mining method is not suitable for extracting trona in this area. Solution mining was chosen as mining method instead of conventional mining method and trona has been extracted with this method since 2005.

Solution mining is done by constructing production units or caverns and operating these units. Production unit consists of two vertical and one directionally drilled (named as horizontal) wells. These well pairs are connected underground via drilling. Solvent is injected from horizontal well then, brine is collected from vertical wells.

Collected brine is fed to process plant with pipelines to produce sodium carbonate and sodium bicarbonate.

Hot water or solvent with containing 2-3 % equivalent Na_2CO_3 content (or Total Alkalinity) and with 60-80 ºC temperature is injected from the horizontal well. This solvent dissolves trona mineral in target trona seam and brine is taken from the vertical wells with 14-15 % Total Alkalinity (TA) with a temperature of 40-50 ºC. When production starts from one unit, total alkalinity (TA) or sodium carbonate content of recovery is mostly under design parameters. When the brine quality of production unit reaches 14-15 % TA, production unit is assumed as **mature unit** or **cavern**. Reaching maturity level takes some time and also there are some factors affecting maturity of production unit in the drilling and the operation part. Injection temperature and injection flow rate are observed as operational factor to see effect on maturity level of production units.

In this thesis, one part of mine site consisting of nineteen (19) units was selected. Daily laboratory analysis from laboratory of company was collected and also daily production data obtained by distributed control system of these units was accumulated. Time dependent regression analysis of injection temperature and flow rate was carried out for all units' operation and laboratory data. Then, operational factors affecting maturity of units is tried to explain by using regression analysis first all production units separately. Moreover, U6, most common trona seam at the study area, is observed for helping production scheduling of mine.

1.2. Problem Statement

In the study area, two vertical wells and one directionally drilled (horizontal) well are drilled at first. Three well combinations including vertical and horizontal wells are named as production unit or cavern. These three wells are connected from underground with directional drilling. Drilling path is made up between wells to extract trona from underground as a solution (brine). Injection starts from horizontal well and brine is taken from vertical wells after the completion of drilling and surface facilities. All wells are used both injection and recovery well for providing equal dissolution of cavern.

At the study area, it is not known that when production units may reach maturity level and how injection temperature and flow rate affects increasing concentration of brine. This problem could affect the mine planning and therefore plant production to some extent. For this reason, regression analysis was done to selected production units. Effect on injection temperature and flow rate on maturity level was explored and maturity time of units drilled in U6 trona seam are tried to estimate.

1.3. Objectives of Study

At the study area, yearly production is 1.5 Mt soda ash and 0.2 t sodium bicarbonate. Production should be sustainable because of coming up to level of maximum production. For production of soda ash and sodium bicarbonate approximately 1,300 m^3/h brine is fed process plant from mining site continuously. Brine fed to process plant should be 14-15 % TA in concentration to avoid increasing consumption of electricity, coal and caustic soda etc. Production scheduling of mining has an important role in order not to cut production. 50 of production cavern should be operated at the same time and at least 5 units should be remained at stand-by position. Therefore, it is necessary to know when production caverns reach process design parameters (14-15 TA %) and how daily operation changes affect maturity of units to do yearly or long term mine and production planning.

In this manner, one part of mine site, containing 19 units has chosen for how operational factors affect maturity of production units. With the knowledge these factors, it is easier to estimate when units are suitable for production of process plant with an optimum condition.

1.4. Research Methodology

The methodology below was followed during the research:

1. Nineteen (19) units were chosen to observe operational factors affecting their maturity.
2. All daily production information from distributed control system of company was collected.
3. Laboratory analysis data of each unit were collected from laboratory of company.
4. Using laboratory analysis data sheet, total alkalinity of each unit in daily basis is calculated using Na_2CO_3 and $NaHCO_3$ concentration of brine, and density of brine.
5. 18,433 data were collected in almost two years.
6. Then, production data sheets were rearranged including solvent flow rate, solvent temperature and brine concentration (TA %).
7. Box-plots were drawn for injection temperature (T), flow rate (Q) and brine concentration (TA %) of each unit.
8. Regression analysis was done by using first 12 and 3-month production and laboratory data and their regression equations were given for each production units, separately.
9. For U6 trona seam, regression analysis was done by using first 12-month production and laboratory data and its regression equations was given
10. For U6 trona seam, maturity time was estimated.

CHAPTER 2

LITERATURE SURVEY

For this topic, solution mining method and literature related to dissolution of trona mineral were reviewed in detail and they are given in this chapter.

2.1. Solution Mining

There are two ways of leaching in solution mining method in study area. First way is leaching via vertical well only and second one is leaching with vertical and horizontal well combinations.

2.1.1. Leaching with vertical well only

Leaching with vertical wells has two main purposes which are production and cavity creation. Some of mine sites which are selecting solution mining as a mining method are performing production with a single well. They may use vertical or single well leaching only for production.

At study area, vertical well leaching is used for only **cavity creation**. Leaching for cavity creation with vertical wells is intended to expand the target area so that it is easy for the horizontal wells to intersect first target vertical well. While drilling of vertical well may complete, sometimes for cavity creation, hot water is injected into well. It helps to increase empty space underground at the bottom of vertical well and also when horizontal wells connecting to vertical wells, because of space underground, it prevents passing path. According to process plant behavior (it means plant can overcome low sodium carbonate concentration), after vertical well is completed, leaching can start with the vertical well alone.

Cavity creation method can be done as;

- First solvent or hot water at a temperature of 60–80°C is prepared at solvent tanks and pumped to wellhead with the help of main and auxiliary pipelines.
- Secondly, solvent or hot water is injected into underground through the tubing into the ore bed where it dissolves trona.
- Then, the soda (brine) solution with partially saturated sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$) returns between production casing and tubing (i.e annulus) to the wellhead.
- Finally, brine coming from the annulus is fed to pipeline (Figure 2). This step is continued until a small target cavity is formed at the base of the vertical well(s).

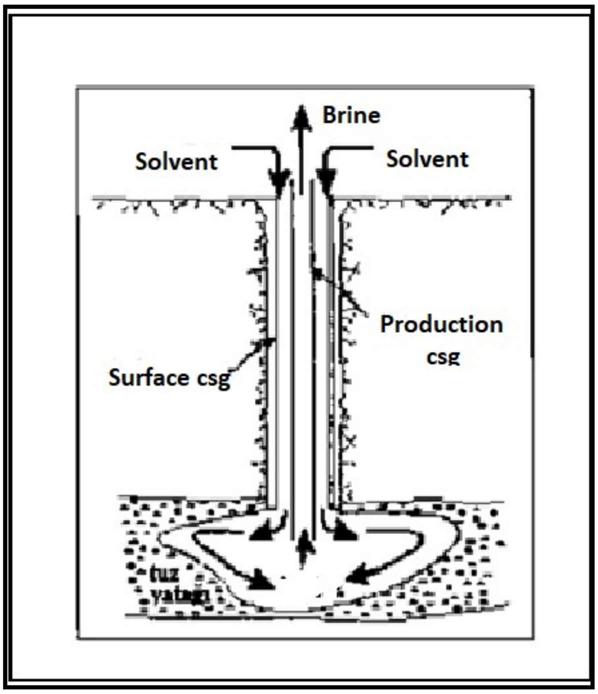

Figure 2. Leaching with vertical well

2.1.2. Leaching with vertical and horizontal well combination

At Eti Soda mine, solution mining method is a rubblized cavern leach method using multiple vertical wells with a horizontal well to connect the vertical wells.

It is planned that the horizontal borehole transitions from a borehole to a zone of permeability as it slightly enlarges. It is also envisaged that this zone of permeability is largest immediately adjacent to the vertical wells and is smallest at the mid-point between the two wells (United States Patent No. US2006/0039842A1, 2006). The drilling and cavern development sequence is as follows for leaching with vertical and horizontal well combination:

- Multiple vertical wells are drilled and completed at the base of either the upper or lower trona ore zones. These wells are strategically located “on-strike” at the bottom of the upper or lower trona ore zones.
- Surface pipelines and instrumentation are installed.
- A horizontal well is strategically located to facilitate connecting the single or multiple small “target caverns” on-strike.
- Upon successfully connecting the target cavern(s) with the horizontal borehole, two vertical wells are utilized as an injection well and either the horizontal well or the other vertical well is used as a production well as solution mining is initiated. The resulting production fluid is about 15 weight percent (wt %) TA as Na_2CO_3 (Figure 3).
- The well modes are reversed (the injection well is changed to a production well and the production well is changed to an injection well) as needed to ensure the symmetry of the caverns.
- Each individual cavern will grow vertically until it encounters a layer of shale, which restricts the vertical cavern growth, and the cavern begins to expand horizontally.
- The cavern continues to expand horizontally until the shale layer becomes unstable, ultimately collapsing and becoming partially rubblized.

- After the shale layer collapses, the cavern again grows vertically until it encounters the next shale layer.
- This process continues until the final shale layer collapses and the cavern lose its integrity (Eti Soda Reserve Report).

Ideal case for solution mining for study area determined by laboratory tests preparation stage of mine and plant construction is injecting 60-80 °C solvent with 2-3 % TA (total alkalinity) from horizontal well and 20 m^3/h average flow rate. And collecting brine almost 10 m^3/h first target vertical well (A) and 10 m^3/h second target vertical well (B).

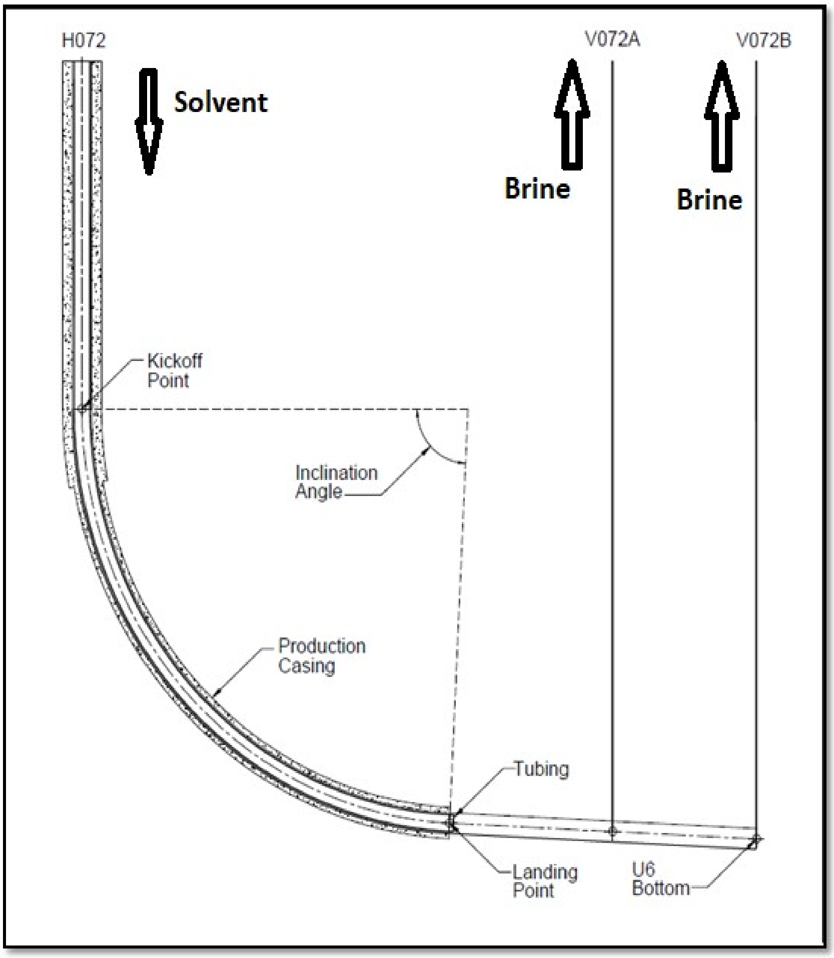

Figure 3. Solution mining with a unit

2.2. Dissolution of Trona

Mechanism of the dissolution of Turkish trona was observed and dissolution rate of trona as a function of brine concentration studied and results were compared with theoretical model (Saygılı & Okutan, 2005). Importance of that study is evaluating trona mineral from technical, economic and environmental perspectives. In this paper, it is stated that dissolution rate is function of time, temperature, concentration and surface area exposed for dissolution. Also it is given that unsaturated exit brines need extra processing and it increases cost.

According to Saygılı and Okutan (1995), dissolution rate affects brine saturation, number of required unit wells and life of unit. Finally, in this paper, it is given that a higher flow rate, increases productivity and reduces the number of wells required for a given production rate.

Furthermore, effect of temperature on dissolution of Turkish trona was observed, trona samples are prepared to measure the rate of dissolution as a function of concentration and temperature (Saygılı, 2003). The experiments were done at different temperature and concentrations. According to experiments they made, Figure 4 and 5 were obtained. Figure 4 shows that as temperature increases, the rate of dissolution increases for all solution concentrations. Also, the rate of dissolution decreases as the concentration increases with constant temperature (Figure 5). It is pointed out that temperature is more important factor at low concentration solutions than high concentration and Saygılı concluded that problem is complex and to find definite answers large scale observations should be done.

Literature could be surveyed only in the point of trona dissolution rate. Starting from this point of view, operational factors affecting maturity of units was observed by using reel production and laboratory data.

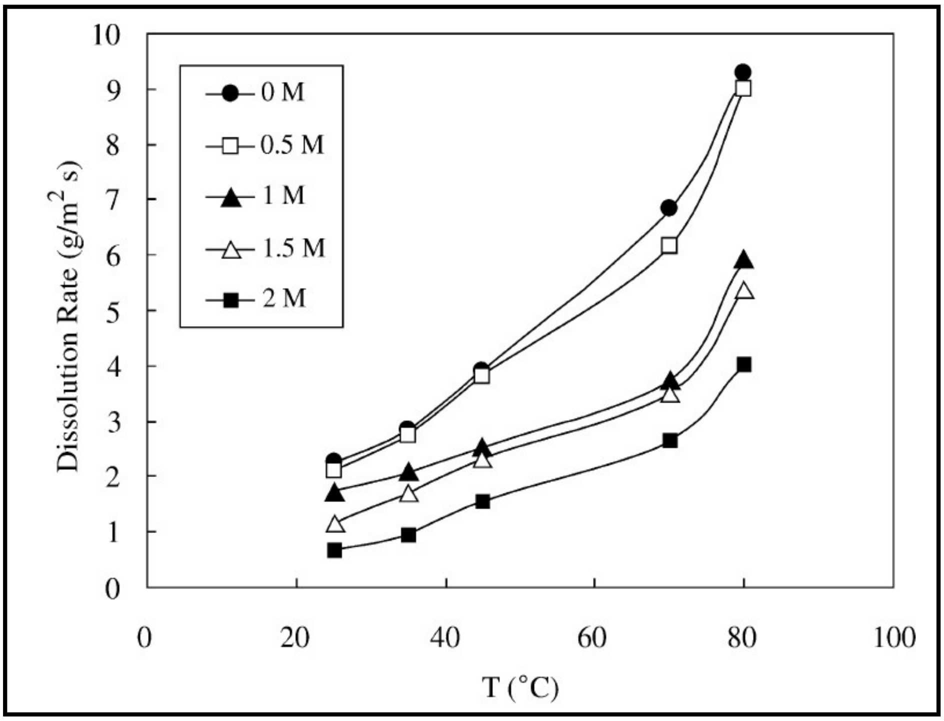

Figure 4. Temperature dependence of trona dissolution rate (Saygılı, 2003)

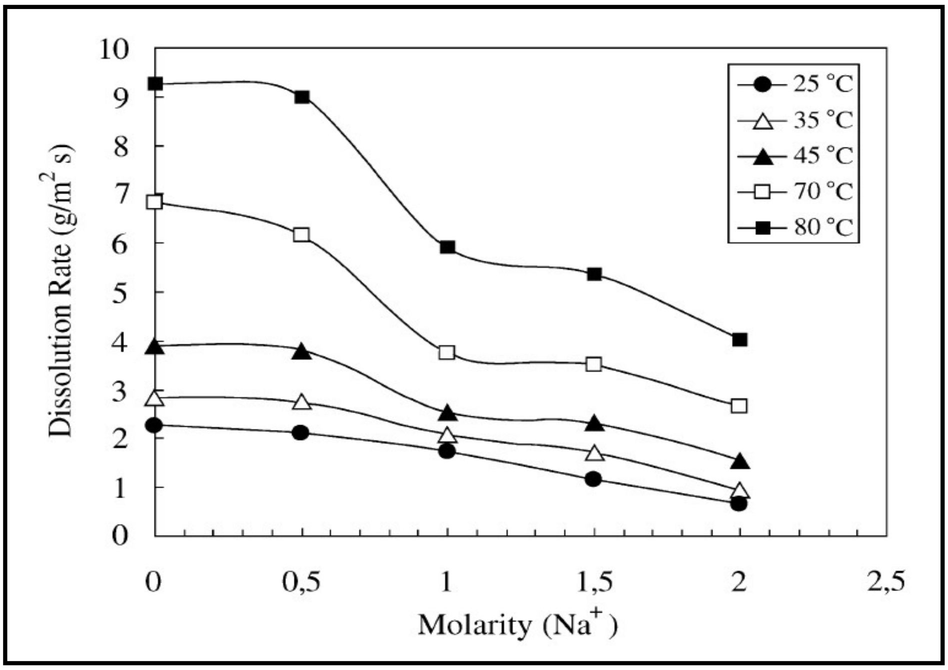

Figure 5. Solution concentration dependence of trona dissolution rate for various temperatures (Saygılı, 2003)

CHAPTER 3

GENERAL INFORMATION ABOUT STUDY AREA

3.1. Location Access of Study Area

Beypazarı Trona Field is located near the town of Beypazarı, Ankara, District, in Central Anatolia, northwest of the capital city of Ankara, Turkey (Figure 6). This area is accessed by approximately 100 kilometers (km) of paved asphalt Ankara - Beypazarı state road D140.

Figure 6. Location of study area

3.2. Infrastructure, Local Resources and Climate of Study Area

Active mining area is about 8 square kilometers (km^2), approximately 800 hectares (ha) limited by Başören, Bağözü and Çakıloba villages. This trona field is largely an agricultural area with low mountain terrain between 780 and 1150 m elevation dominated by barren hummocky terrain with little vegetation. For agricultural purposes, plain type lands are used. Agriculture is on the score of irrigation, growing carrot, tomato, pepper, onion, cabbage and other green vegetables and vineyards.

Area is in mid-Anatolian climate region; summer months are dry and hot and during the winter months, the weather is cold and rainy. December, January, April and May are the rainy seasons. The mean annual maximum temperature is 19.1 ºC and minimum is 7.1 ºC. The mean relative humidity is 61 %, mean annual evaporation is 1,075.8 millimeters (mm), the mean annual precipitation is 410.1 mm, average wind speed is 1.4 meters per second (m/s) and maximum is 19.3 m/s.

The location is serviced by 154 and 34.5 kilovolt (kV) power lines and paved roads.

3.3. Geology of Study Area

The Beypazarı district lies between the coal mining town of Sarıyar and Beypazarı. It is in an area of about 65 km in length in a 1,500 km^2 area. Sedimentary and volcanic-sedimentary lithological units, deposited in lacustrine and alluvial environments, are about 1,000 m to 1,200 m thick and uncomformably overly a Paleozoic basement of granite, granodiorite, and metamorphic rocks (CdFI, MDPA, Sofremines, & Teknomad, 1991). The Basin formed initially in the Mesozoic with major deposition in the Tertiary Miocene and additional filling in the Pliocene.

The Basin is bound to the north by a system of anticlines and synclines, bound to the south by the Zaviye Fault, and bisected by the Kanlıceviz Fault from north to south, defining the Elmabeli and Ariseki sectors.

There are 26 trona beds, 13 of which are considered to be of economic grade and thickness. They occur in the Miocene Hırka group within beds mainly of oil shale, claystone, tuff, and dolomitic limestone.

3.3.1. Stratigraphy

The Pliocene and Miocene Formations characterize the Basin. The general features of the formations from the oldest to the youngest are taken from are summarized in this part. A generalized stratigraphic sequence of the Basin with details of underlying Neogene and older basement rocks is illustrated below in Figure 7.

Boyali Formations (Tb): The formation crops out in a very limited area in the western part of the trona field and is composed of conglomerate and sandstone with claystone interbeds. The upper part has two lignite seams and conglomerates including volcanic fragments. The thickness of the formation is about 200 to 300 m.

Hırka Formation (Th): The trona bearing formation consists of bituminous shales, claystones, and siltstones below the trona zone and alternating claystone, bituminous shale, and tuffite above. Brecciated tuffites below the upper trona zone are typical. The oil shales may be thinly laminated or brecciform. The formation thickness is up to 300 m. There are 13 major trona beds, 6 upper and 7 lower beds separated by 25 m of interburden of claystone, bedded tuff, and oil shale (Figure 8).

Karadoruk Formation (Tka): This formation is made up of dark gray limestones with chert layers and hosts an aquifer. It is conformable with the Hirka and Sarıağıl Formations at its lower and upper contacts, respectively. The thickness in general is about 15 to 20 m, and up to a maximum.

Sariağil Formation (Ts): This formation crops out in the vicinity of Sarıağıl village in the northern part of the Basin and consists of greenish-gray claystone and tuffite with some medium bedded limestone. Its thickness ranges between 40 and 80 m.

Çakıloba Formation (Tç): This formation is composed of limestones with chert, and alternating beds of tuffite, claystone, and marl at the upper and lower levels, respectively. It hosts the second aquifer above the trona zone. The rock units in the formation have a fractured structure and solution features. The thickness of the formation through the Basin ranges between 40 and 70 m.

Zaviye Formation (Tz): This formation largely crops out in a large part of the Arıseki sector and in the southern part of the Basin. The formation mainly consists of alternating layers of marl, claystone, and tuffite with minor layers of limestone in the upper part. Its thickness reaches up to 200 m south of the Zaviye Fault and becomes thinner towards the northern part of the Basin. The formation is unconformable over the Çakıloba Formation.

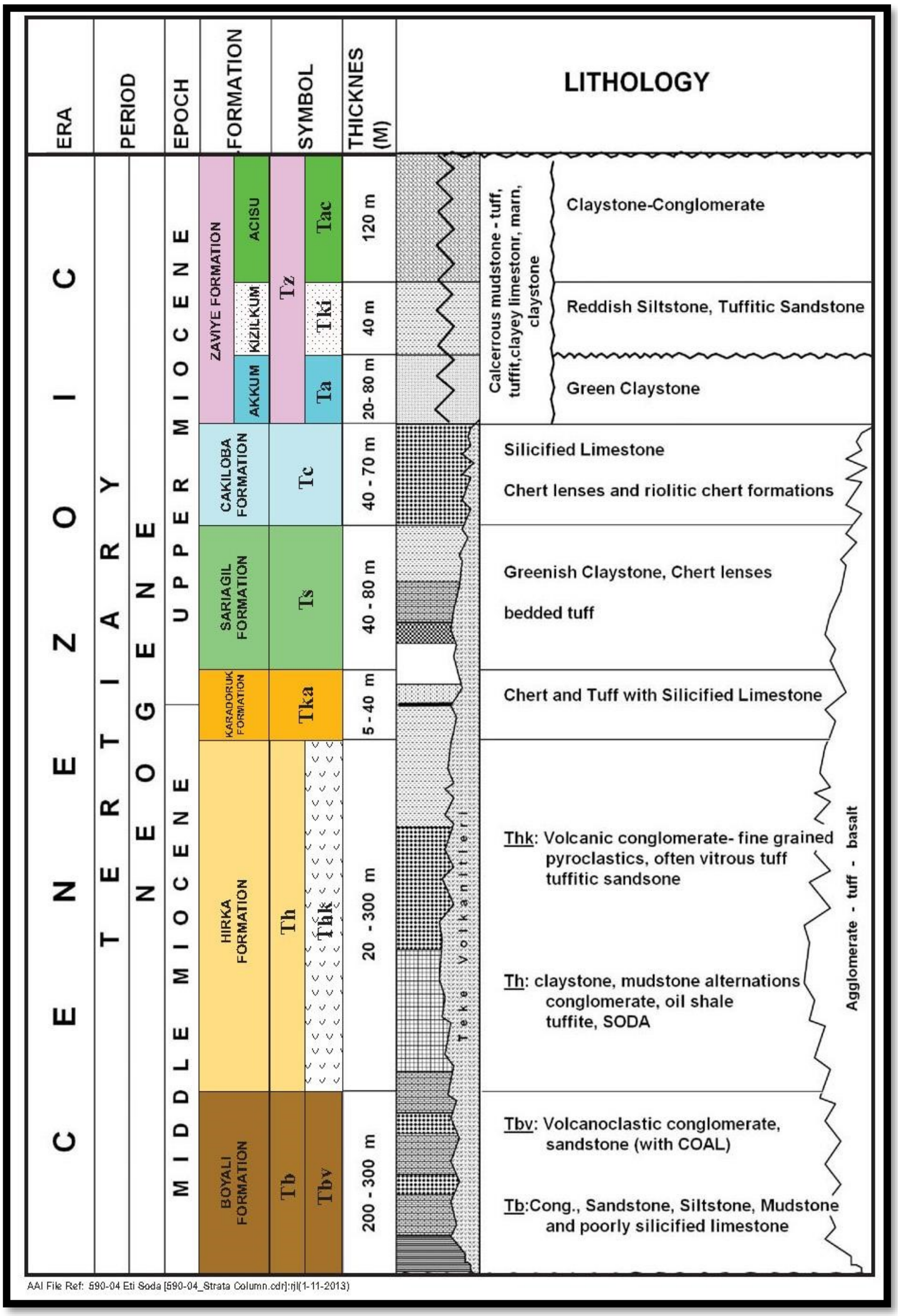

Figure 7. Stratigraphic section of the Beypazarı trona basin (Özgüm, Gökmenoğlu, & Erduran, 2003)

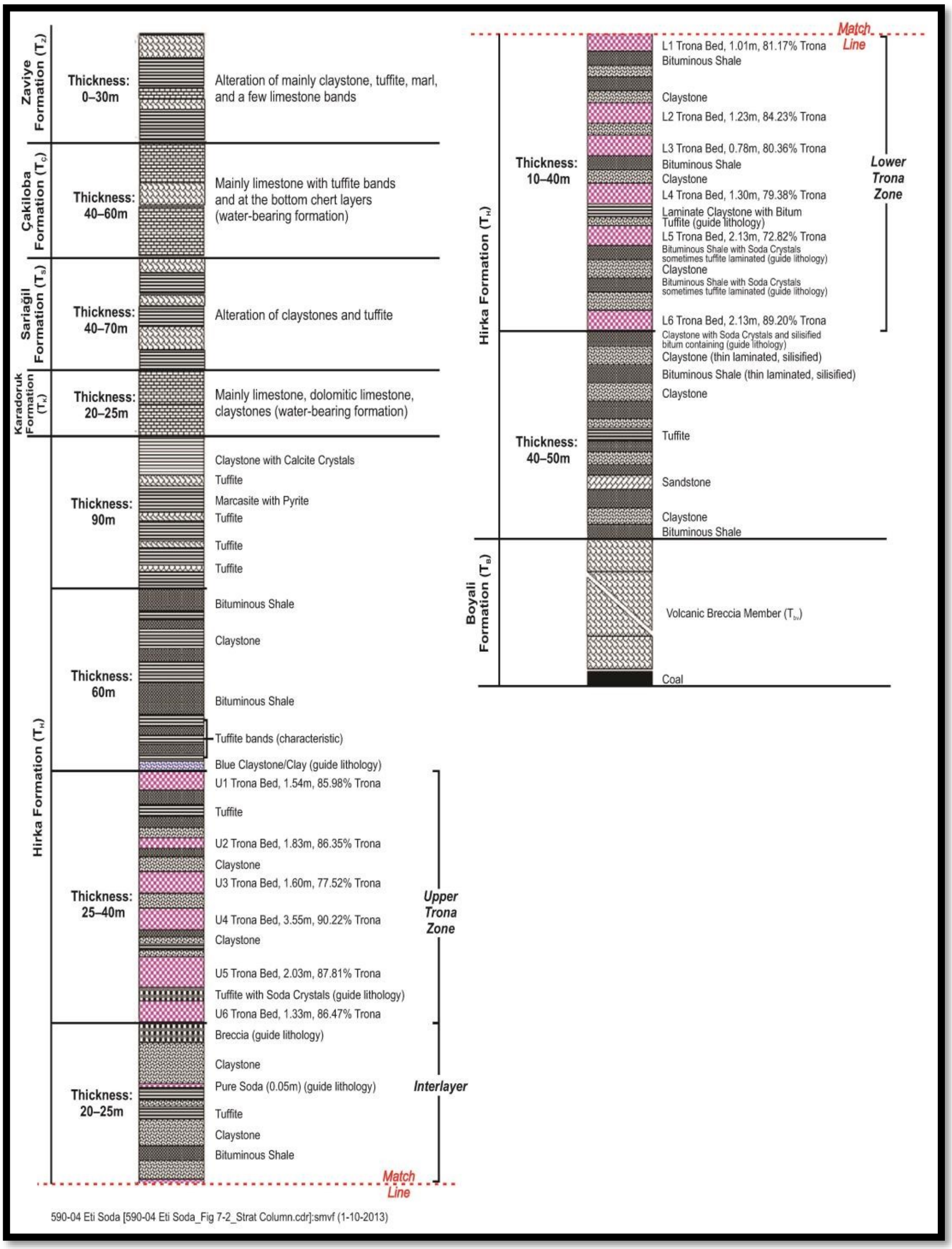

Figure 8. Beypazarı stratigraphy of upper and lower trona beds (İnceefe & Çakmakçı, 2002)

3.3.2. Regional and Property Structure

The Basin developed during the Pontide orogenic event from the Jurassic period to Miocene epoch. It is characterized by accretionary deformation from the Mesozoic through Tertiary times at its active margins with periods of shortening and extension; most were related to the dynamics of the northward subduction of the Tethyan oceanic event (Okay, 2011).

The Pontide orogeny consisted of three plates or terraines (Sakarya, Istanbul, and Strandja) with independent histories prior to the Early Cretaceous period. The Basin is influenced largely within the Sakarya terrain, with sedimentary sequences developing from the Lower Jurassic (Okay, Geology of Turkey: A Synopsis, 2008) period.

The Miocene collision between the Arabian and Anatolian plates resulted in large lakes in the western and central Anatolia region supplied by sediments from uplifted ranges of older sedimentary and metamorphic rocks and nearby calc-alkaline volcanics. The Neogene Basin is bounded to the north by the West Pontide mountain belt and to the south by the Middle Sakarya igneous and metamorphic massif and is characterized by extension and strike-slip faulting (Figure 9).

The Basin is defined by a number of structures:

- Zaviye, Kanlıceviz, and Elmabeli Faults
- Çakıloba Fold System of anticlines and synclines
- Secondary faults developed parallel to and/or intersecting the major fault systems
- Bedding planes generally dipping towards the southeast

The Zaviye Fault strikes N60°E, dips 80–85°, is visible on the surface along 5 km, and is the southern boundary of the Basin. No trona zones were reported to have been penetrated during drilling in the southern part of this fault. It is considered a wrench fault to the west and a strike-slip fault to the east. The Çakıloba Fold and Fault System strikes N73^{O}E bounding the Basin to the north. Some isolated occurrences of trona beds occur to the northwest of the zone.

The Kanlıceviz Fault separates the Basin into the Ariseki (Eastern) sector and the Elmabeli (Western) sector, striking N20°W and dipping 35–60°southwest. It is a thrust fault and cuts both the Zaviye Fault and the Çakıloba Fold.

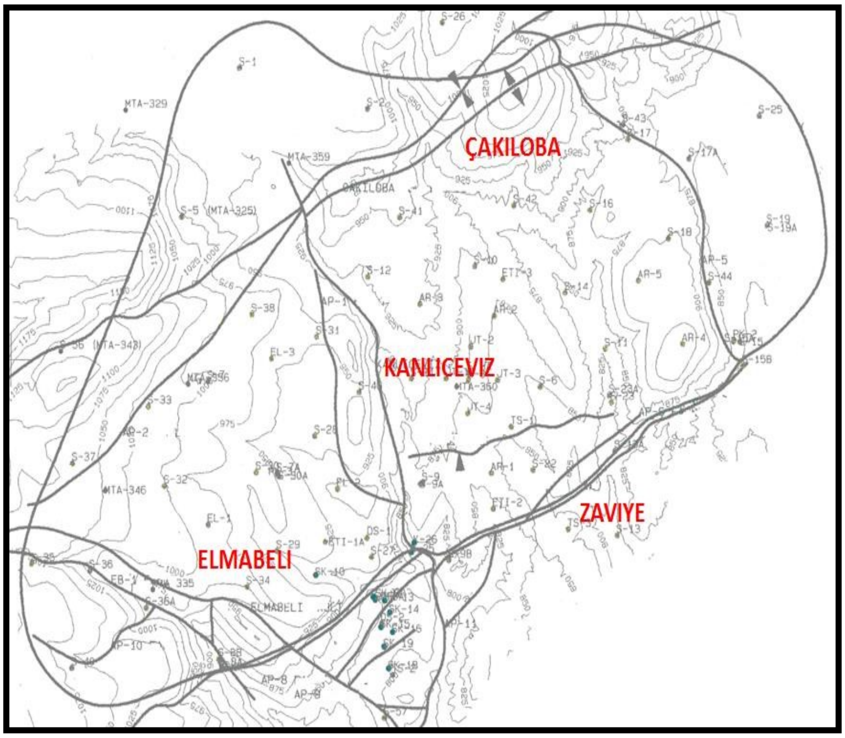

Figure 9. Faults and folds of study area

The Elmabeli Fault is a thrust fault on the southwestern end of the Basin and strikes approximately east-west.

The Çakıloba Fold is a system of anticlines and synclines striking N73°E with a 7.5-km surface expression in the northern part of the Basin. It is strongly monoclinal with dips in the southern flank at about 5–6° southwest and 55–60° in the northern flank (Figure 10).

Figure 10. Folding system at study area

3.3.3. Hydrology

Two major aquifers are present at the study area, both are above the trona bed in the Basin.

The Karadoruk Formation (Tk), about 150 m above the trona beds, is composed of cherty limestone, chert, tuff, claystone, and mudstone. Where fractured, the limestone and chert are water-bearing above the confining layer.

The Çakıloba Formation (Tç) is fractured limestone with chert and exhibits karst with bedded tuff, lower interbeds of claystone, and mudstone. The upper and lower bedded tuff, claystone, and mudstone layer are impermeable lithologic horizons.

3.3.4. Hırka Formation (Trona Bearing Formation)

In the study area, principal minerals are trona ($Na_2CO_3NaHCO_3.2H_2O$) with minor nahcolite ($NaHCO_3$). Trona mineral is seen white to gray honey color, crystalline, prismatic to massive in bedded layers in Hırka Formation. Thirteen (13) major trona beds (7 upper and 6 lower layers) are determined by drilling data of drill holes completed for exploration and production well. The exploration and production drill holes and section of trona seams are given in Figure 11 and Figure 12.

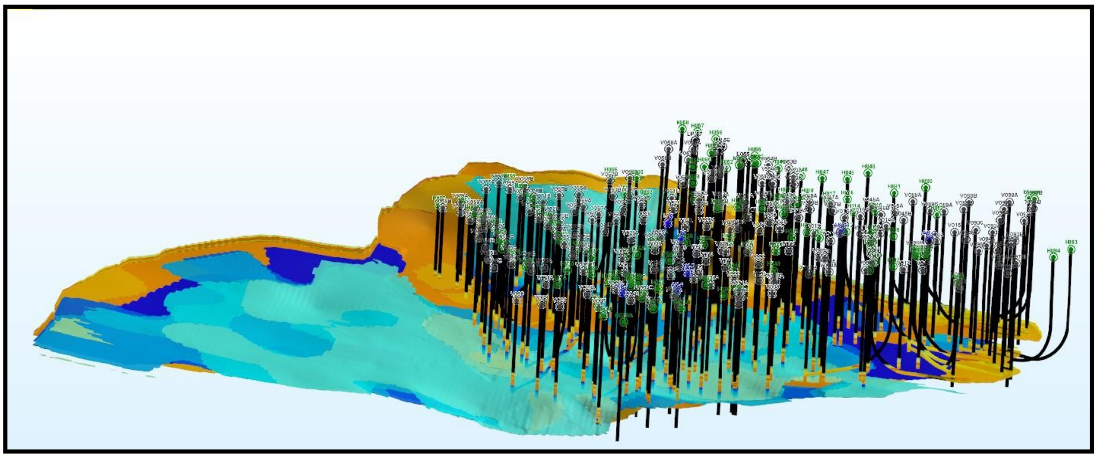

Figure 11. 3D view of upper and lower trona and drillholes

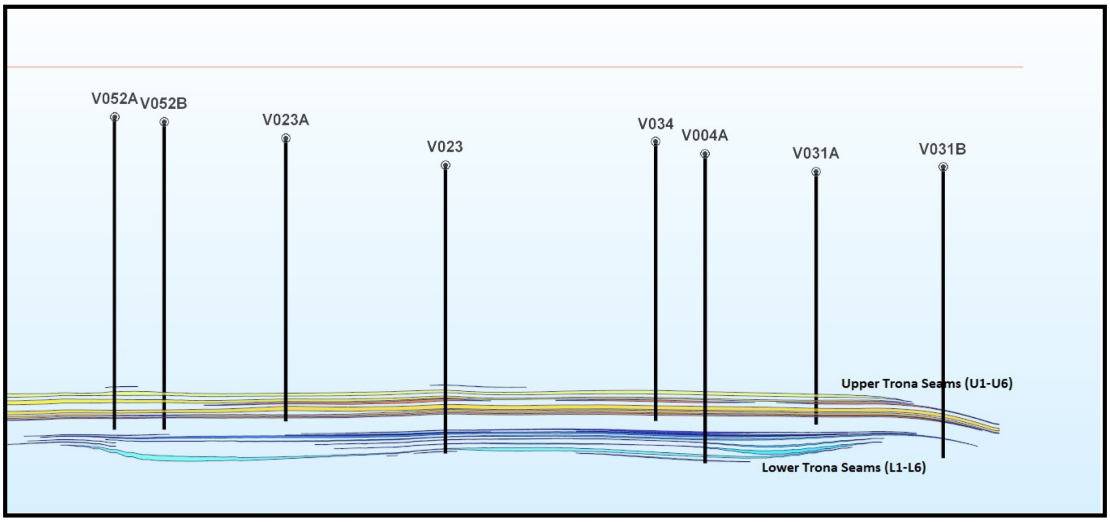

Figure 12. Section view of trona seams

Average seam thickness is 3.1 meters for upper zone and 2.1 meters for lower trona zones. Overall, the average thickness is 2.9 m and U4 is the thickest bed averaging 4.5 meters thickness.

The deposit overall TA is 58.8%; the upper trona zone is 59.3% and the lower zone is 57.1%. The highest grades are in U4 at 62.5% TA and 44.1% sodium carbonate. The lowest soda values are in U1 and L1. The highest bicarbonates are in U1 at 46.7%.

- **Upper Layers:**

-U1: Average grade is 51 % Total Alkalinity (TA) (Na_2CO_3 is 21.6 % and $NaHCO_3$ 46.6 %) and this trona layer has highest bicarbonate content. Its average thickness is 1.8 meters.

-U2: Its TA is 60.2 % where Na_2CO_3 is 41.2 % and $NaHCO_3$ is 30.7 % and average thickness is 2.9 meters.

-U3: Average grade of this trona layer is 58.8 % TA with 2.4 m average thickness.

-UX: This bed is present over most of the Basin and its distribution is like lensoid with 1.9 m average thickness and 47.2 % TA. Na_2CO_3 content is 34.3 % and $NaHCO_3$ is 20.5 %. UX bed has highest insoluble content with 31.7 %.

-U4: This bed is the thickest and the highest grade bed with 4.5 m average thickness and 62.4 % TA (containing 44.1 % Na_2CO_3 and 29.1 % $NaHCO_3$).

-U5: Its average thickness is 2.5 m and grade is 60.8 % TA (43.3 % Na_2CO_3 and 27.7 % $NaHCO_3$).

-U6:1.7 meters in average thickness and 58.4 % TA in average grade.

- **Lower Layers:**

-L1: Soda is 38.4 %; bicarbonate is 24.2 % and its average thickness is 1.4 meters.

-L2: Average grade is 59.3 % TA and average thickness is 1.8 meters.

-L3: Its grade is 59.6 % TA. Na_2CO_3 is 43.4 % and $NaHCO_3$ is 25.7 %.

-L4: This bed has 55.9 % TA (40.3 % Na_2CO_3 and 24.9 % $NaHCO_3$) with 1.7 m average thickness.

-L5: 2.5 m thick with a TA of 56.0 %.

-L6: 2.8 m thick with a TA of 57.4 %.

-L7: It has small footprint of 2.2 m thickness and 55.8 % TA.

CHAPTER 4

PRODUCTION UNITS IN BEYPAZARI TRONA MINE

4.1. Drilling and Completion of Units

Solution mining is used as mining method at study area. This method is done via production wells. Drilling steps of wells and completion of units were clarified in this chapter.

Two (2) vertical wells and one (1) directionally drilled or horizontal well comprise one production unit. In Figure 10, schematic view of the production unit is given. It shows that top view of horizontal well and its landing point and vertical wells. To construct one production unit, firstly vertical B well is drilled and then drilling of vertical A well is completed. Finally, horizontal well shall be drilled and this well is connected with vertical A and B wells underground via drilling. The distance between landing point (LP) of horizontal well and vertical wells are almost 75 meters (it can change according to geological conditions).

According to top view of the production unit, inner elliptical shape shows production area of unit. Boundary of semicircle with a 35 meters' radius of and rectangle with a 75 meters long edge shows production area of unit. Trona reserve of the unit can be produced throughout all trona seams. Pillars are left between production units to make production safe and safety zone of production units at least 10 meters (Figure 13).

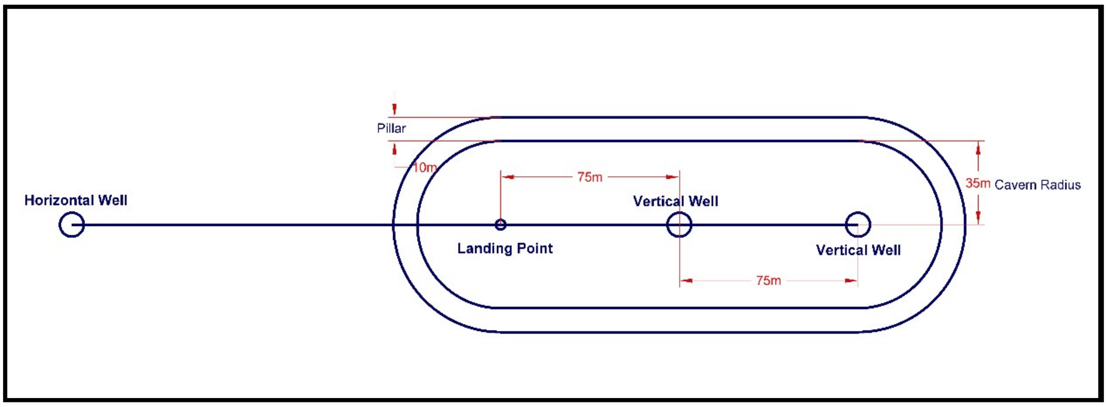

Figure 13. Schematic view of unit

Before starting a drilling, well pad is prepared for drilling rig and its facilities. And then rig is mobilized well pad and after rising derrick drilling shall start (Figure 14).

Figure 14. Preparing drilling

Figure 15. While drilling a vertical well with rotary-table rig

In the study area, two different types of drilling machine are used for the completion of drilling, named rotary-table rig and truck-mounted machine (Figure 15&16). For vertical well drilling both drilling machine is suitable but because of engine capacity and directional drilling part, horizontal drilling can only be completed with drilling rig.

Figure 16. Truck-mounted drilling machine

4.1.1. Drilling and completion of vertical wells

At the mine site, the presence of underground water (aquifer systems) and depth of trona seams are take in account. The production wells are designed for protecting water systems. It means that production wells consist of two (2) different casing pipes (called surface and production casing) and one (1) production pipe (i.e. tubing). In order to prevent water pollution, two times cementation works shall be done. Drilling of vertical well steps given below (Beşir & Kafadar, 2018);

a) First, conductor hole drilling is completed from 0 to maximum 10 meters (minimum 6 meters) with 17 ½-inch (444.5-mm) diameter drill bit to make well more stable and continue drilling without deviation and 16-inch (406.4-mm) with specifications J55-65ppf –BTC-R2 conductor pipe is run in the hole. Conductor pipe length can be changed according to surface condition (ex. filled well pad). And then, hole is cemented with cement slurry with a specific gravity (SG) of 1.85 (Figure 17).

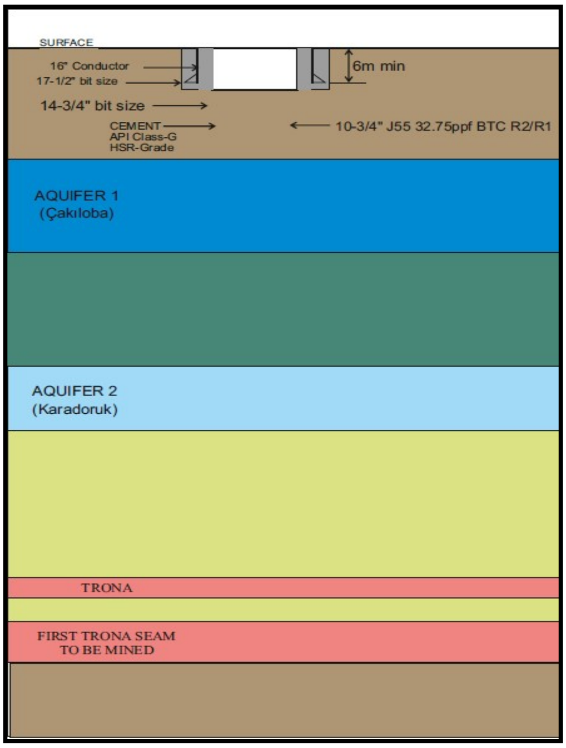

Figure 17. Conductor drilling of vertical well

b) After twelve (12) hours wait for cement, until the underground water levels, drilling shall be continued in the hole (RIH) with 14¾-inch (347.6-mm) diameter about 250 meters and almost 20 meter gap is left to prevent mixing underground water with solution. When drilling is completed to 20 meters bottom of second aquifer which is called Karadoruk formation, second aquifer (limestone) can be checked with electrical logging (gamma ray probe) and geological cuttings, and 10¾-inch (273.0-mm) diameter (with a technical specification J55-32.75 ppf-BTC-R2/R1) surface casing pipes are set down at least 20 meter below bottom of second aquifer. After lowering down the casing pipes, these pipes are cemented with G-Class cement. This step called Spud I is completed with this cementation process (Figure 18).

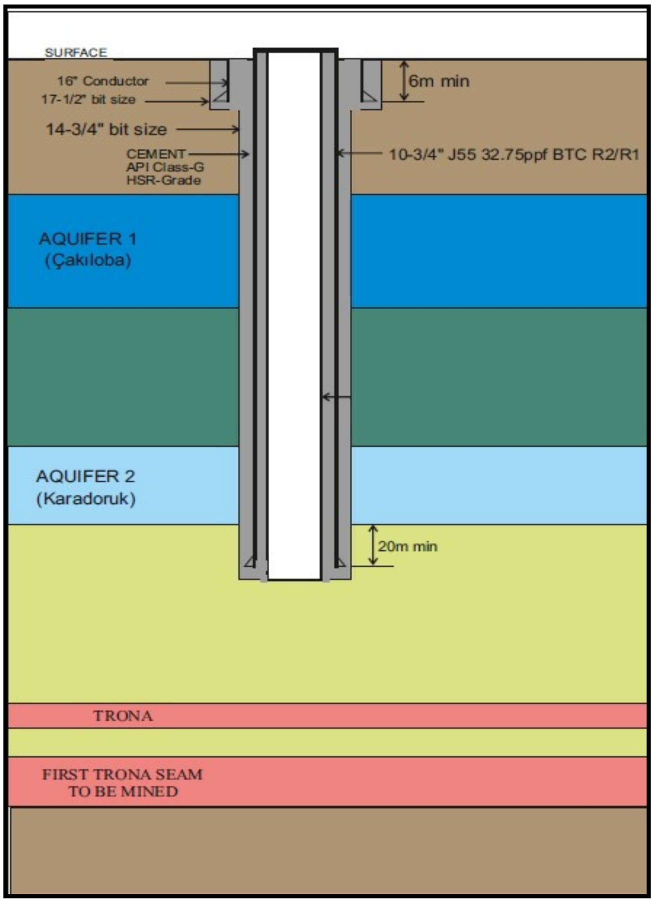

Figure 18. Spud I drilling of vertical well

c) After two (2) days of waiting for cement curing, drilling shall be continued to target trona seam almost 400-450 meters in depth with 9½-inch (241.4-mm) diameter drill bit. When the drilling reaches target trona seams' bottom, electrical logging can be performed to determine the thickness of seam and starting and ending depth of seams. According to these data, 7" diameter J55 (20 lbs/ft) + P110 (29 lbs/ft), BTC-R2/R1 production casing pipes are prepared and sent in to target trona seams' roof given Figure 19. And then cement is pumped to well and well is waited two (2) days for curing (called Spud II).

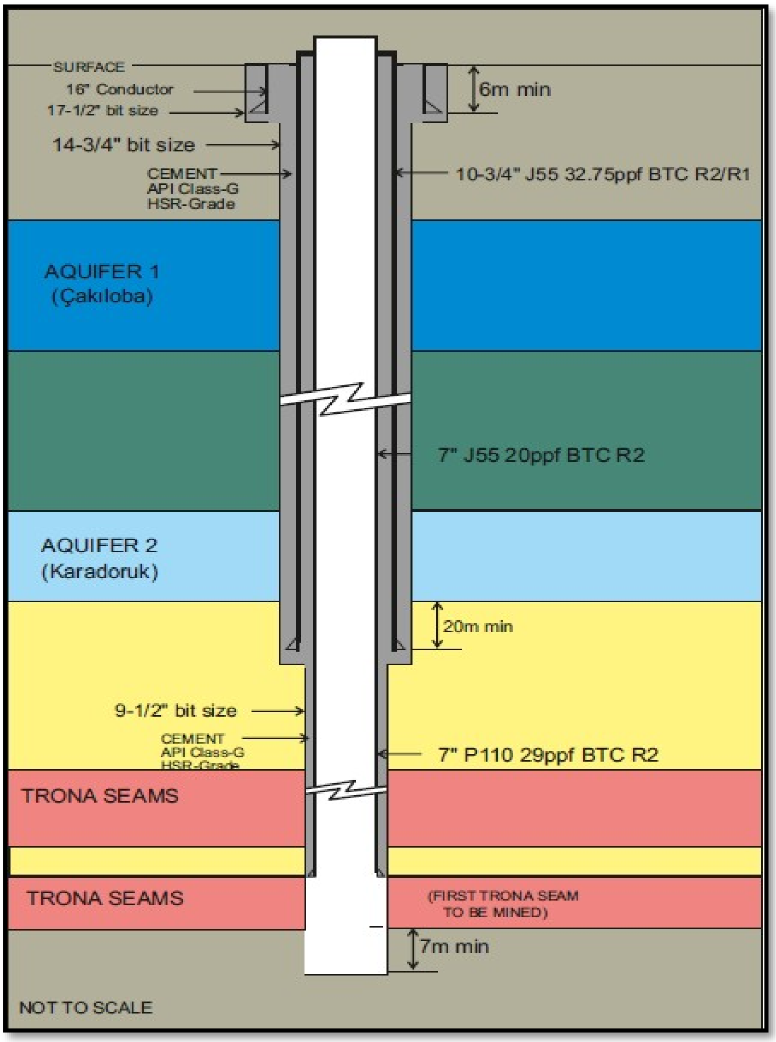

Figure 19. Spud II drilling of vertical well

d) Finally, in order for doing initial leaching and production, 4-inch-diameter (101.6 mm) tubing string (J55 in R2) tubing pipes shall be run in to hole to target seams' floor (Figure 20).

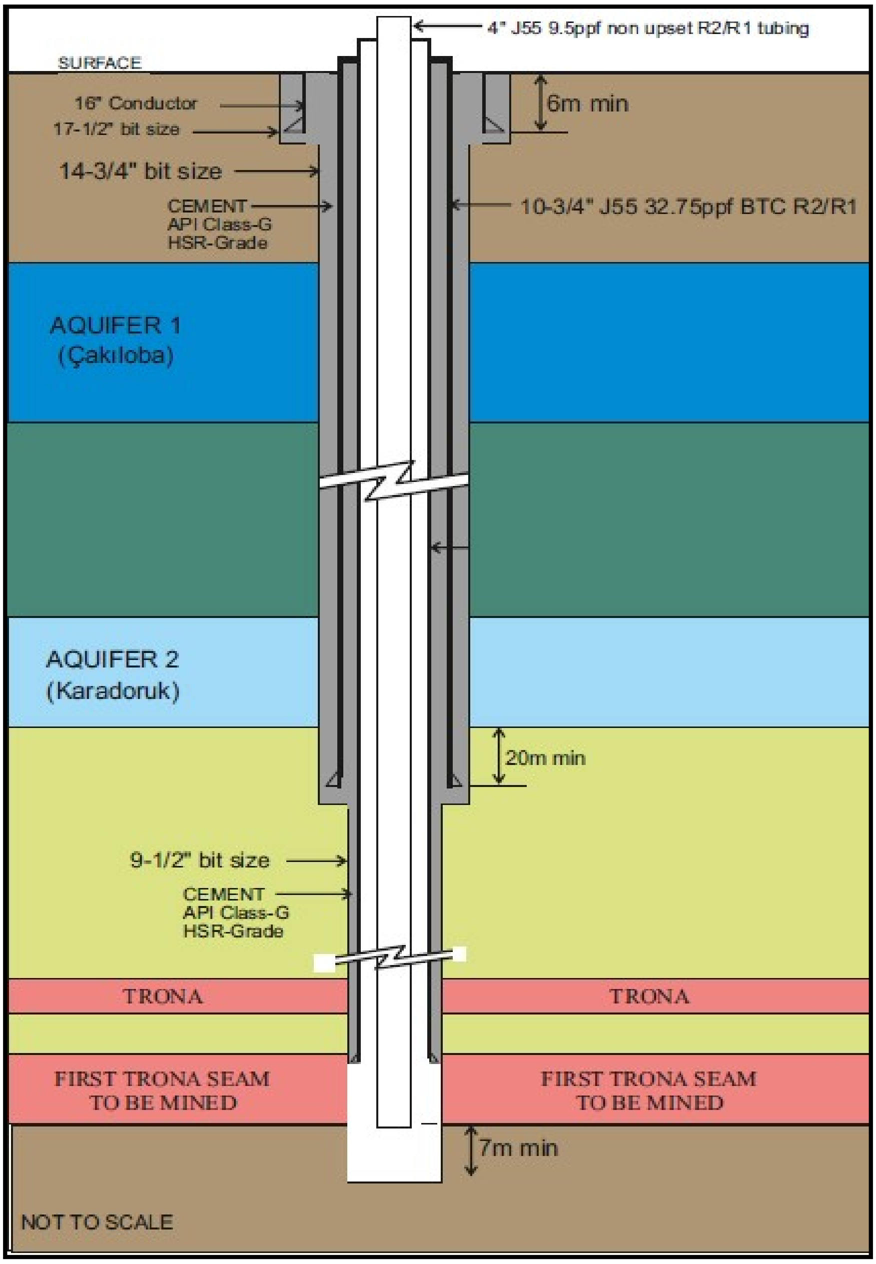

Figure 20. Schematic view of vertical wells

And then, surface facilities are completed;

- Firstly, well tree is connected to casing and tubing pipes with valves and other auxiliary equipment such as choke, hanger (Figure 21).

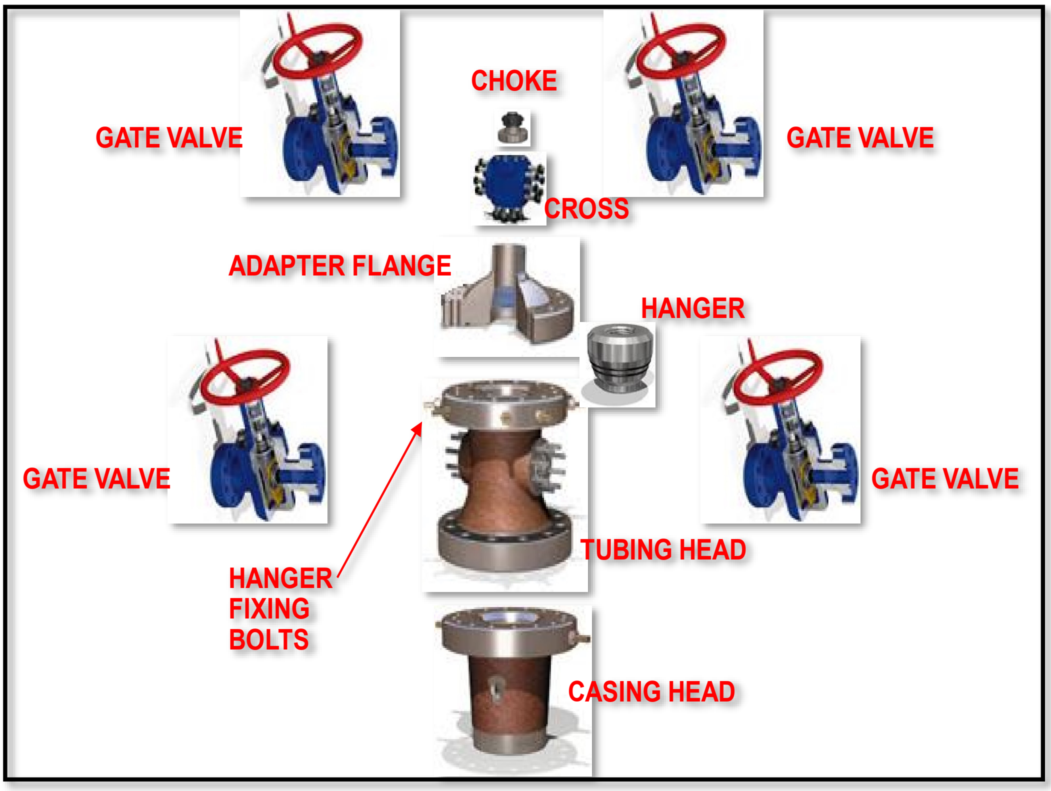

Figure 21. Elements of well tree

- Then, flow meter, pressure transmitter and control valves are connected to branch pipes and these pipes are welded to main pipeline. And electricity connection of these devices is completed.
- Finally, well is ready for operating (Figure 22 and 23).

In wellhead, there are two parallel pipelines, one of them is solvent injection line (at the top) another one is brine recovery line (at the bottom). Four valves in the well tree are used injection or recovery inside tubing or casing pipes.

If production well is used for injection well, solvent is injected from solvent tanks located in the plant and comes through main pipeline to branch line. Solvent passes through flow meter, automatic control valve and pressure transmitter and goes to underground.

If production well is used for brine recovery well, brine comes from underground and passes manometer and flow meter and it connects branch pipeline to main pipeline. And then all brine collects in the plant in brine tanks.

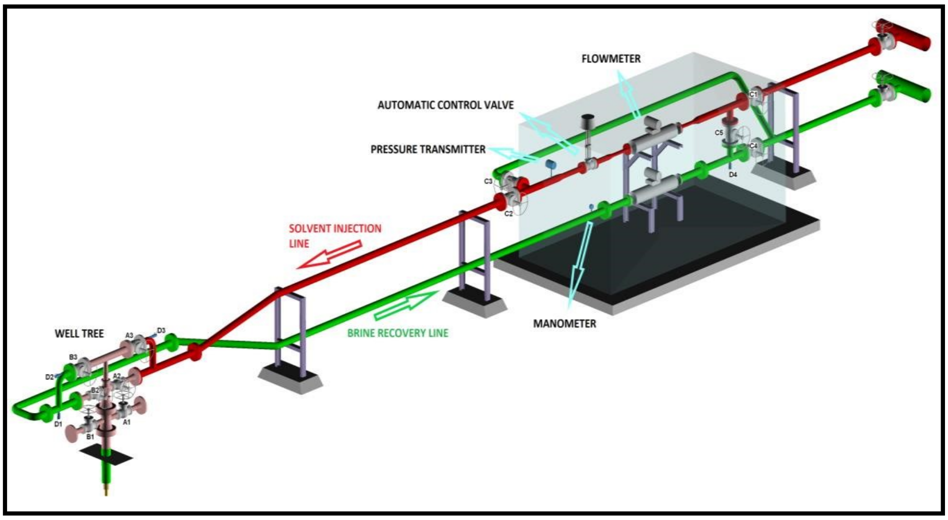

Figure 22. Schematic view of wellhead of production wells

Figure 23. Wellhead of production well

4.1.2. Drilling and completion of horizontal wells

As explained in Section 5.1, conductor and surface the casing drilling (named as Spud I) at horizontal or directionally drilled well is the same as vertical well drilling. For vertical wells, drilling can be completed with drilling rig and its rotating all drilling pipes. While drilling formation and adding new drilling pipes, drilling can be continued until intended depth.

Vertical well drilling consists of drilling rig, drilling pipes. In addition to vertical drilling, horizontal drilling consists of MWD (Measuring While Drilling) system and Steerable down hole motor or Positive Displacement Motor (PDM). MWD and PDM (Figure 24) are called as Bottom-Hole Assembly (BHA).

Inside the PDM, there is a rotor that allows drilling mud inside to pass through the in-hole and to change moving to rotational motion. Thus, only PDM can rotate instead of rotating of whole drilling pipes. In this way, drilling can be deviated to intended direction with determined deviation angle.

MWD (Measuring While Drilling) system takes some data while drilling. Drilling worker shall be informed with these data about where the bit is going. Inside the MWD device, there are sensors which are accelerometer and magnetometer to follow drilling pipes inclination and orientation. Inclination shall be determined with accelerometer (as accepted vertical is 0^o, horizontal is 90^o) and azimuth shall be determined with magnetometer (using world magnetic area).

Data collected by sensors is transmitted to the surface in radio waves. Every piece of drilling pipe, MWD shall take a set of data and save in the computer on surface; it shall be changed to numerical coordinate values. At every drilling pipe (13 meters) the location of wellbore can be calculated.

After Spud I drilling, borehole starts to deviate with a radius around 180-200 meters. This point is called as Kick of Point (KOP) and deviated drilling can be done with special equipment and drilling pipes having 0.5°/m deviation and mud motors explained above.

With 9½-inch (241.4-mm)-diameter drill bit send into hole together with Positive Displacement Motor (PDM) of 172 mm outer diameter. Drilling shall be continued with built up to nominally through the roof of the initial leaching seam. And then, wire line logging shall be performed to check if drill bit hit target seam appropriately or not. If the point reached is correct, this point is named as Landing Point (LP).

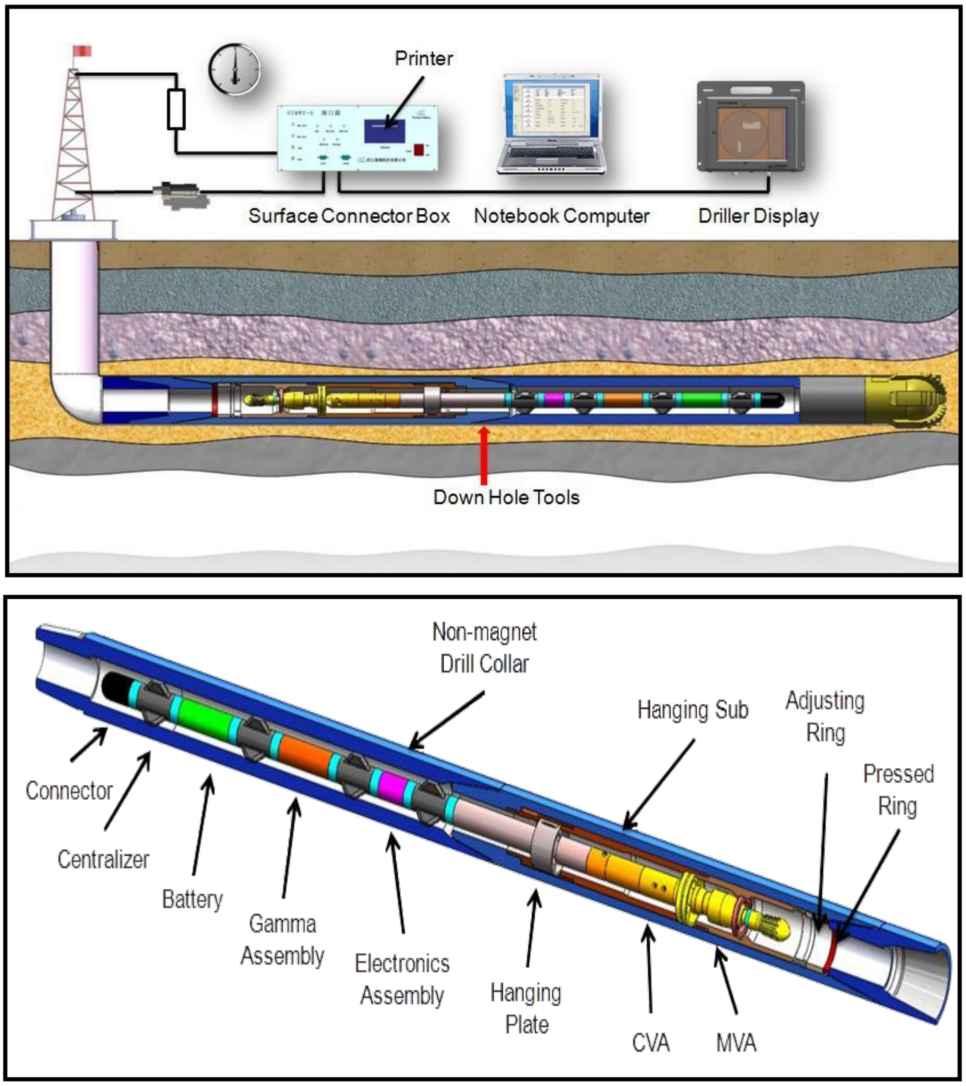

Figure 24. Measurement while drilling system and down hole tool (Wireless Measurement While Drilling, n.d.)

After Landing Point is defined, 7"-diameter J55 (20 lbs/ft) + P110 (29 lbs/ft), BTC-R2/R1 production casing pipes are prepared to run in the hole. And cementation shall be performed to stabilize production casings.

4.1.3. Intersection of horizontal well with vertical well

Drilling with PDM shall continue until 60 meters to vertical well and target-hitting probe run into the vertical borehole. Accuracy, azimuth, inclination and distance data shall be collected with it. And then horizontal well shall connect vertical well under the guidance of target hitting probe.

After the wells are connected underground, 4-inch-diameter tubing pipes are settled down to horizontal bore hole as it will be almost one more piece than casing pipes.

4.2. Operational Factors Affecting Maturity

The mining site is divided to two sectors called Elmabeli and Arıseki in Beypazarı trona mine. Existing production area is in the Arıseki sector given in Figure 25. For this thesis, nineteen (19) production units circled with red color in Figure 25 were chosen from this sector to observe the operation factors affecting the maturity of units.

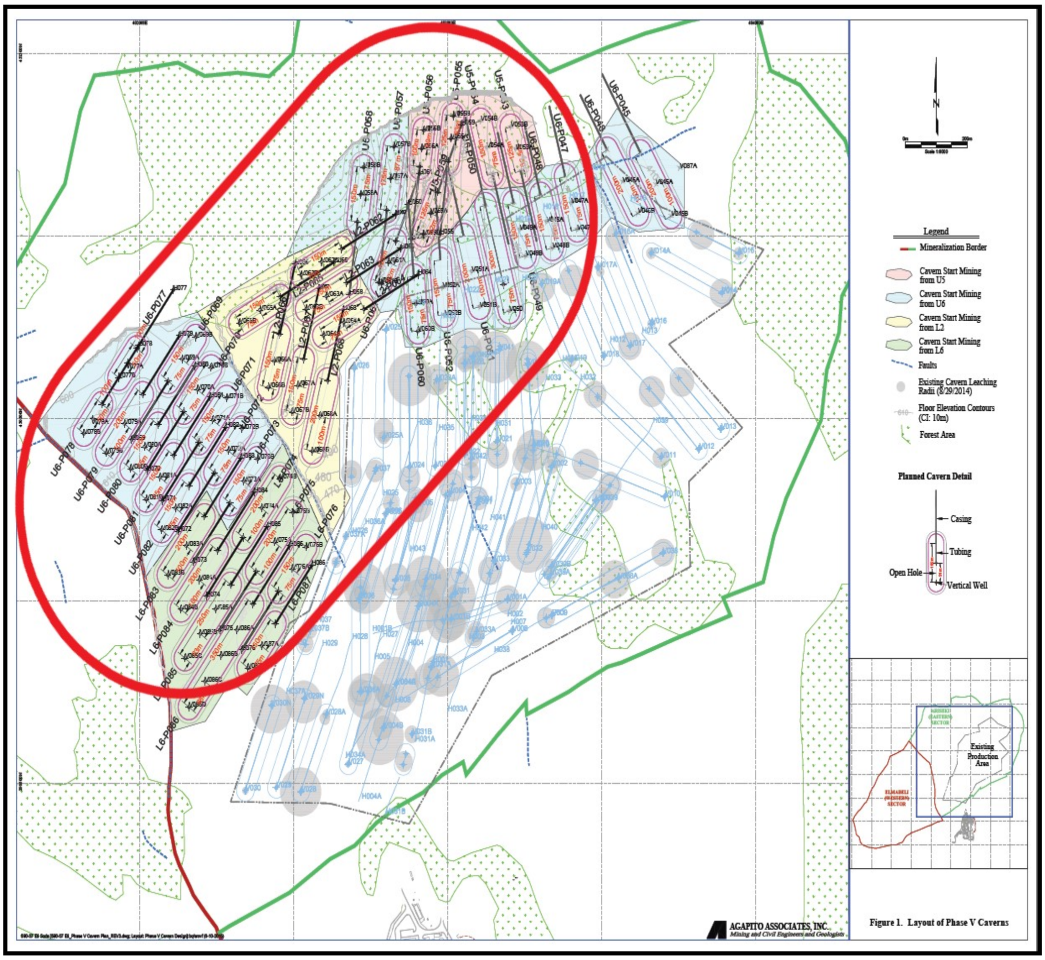

Figure 25. Schematic view of production area of mine site

These production units were drilled in different seams which are U5, U6, L3 and L6. Firstly, production data was obtained from company and they were tabulated in daily basis including injection temperature and flow rate for each unit.

Secondly, laboratory analysis information was acquired from company. The information includes the data about concentration of Na_2CO_3 and $NaHCO_3$ and density of brine. From these values, total alkalinity (TA) in percentage was calculated for all production units. Table 2 is given as an example of laboratory analysis table. TA % values were added to production data list.

Table 2. Laboratory analysis of PU51 unit (first 15 days of production)

Time (h)	**d (g/cm^3)**	**Na_2CO_3 (g/l)**	**$NaHCO_3$ (g/l)**	**TA (g/l)**	**TA (%)**
24	1.16	115.6	70.5	160.1	**13.8**
48	1.16	116.4	69.6	160.3	**13.8**
72	1.15	110.5	67.6	153.2	**13.3**
96	1.15	112.0	68.5	155.2	**13.5**
120	1.10	69.2	55.1	104.0	**9.5**
144	1.11	74.6	59.2	112.0	**10.1**
168	1.11	73.1	59.7	110.8	**10.0**
192	1.11	71.0	57.3	107.2	**9.7**
216	1.11	79.0	60.0	116.9	**10.5**
240	1.13	95.8	65.4	137.1	**12.1**
264	1.12	77.5	65.5	118.8	**10.6**
288	1.12	82.5	66.4	124.4	**11.1**
312	1.12	76.7	63.3	116.6	**10.4**
336	1.12	77.5	61.1	116.1	**10.4**
360	1.12	84.4	62.2	123.6	**11.0**

Brine has two components which are sodium carbonate and sodium bicarbonate. Total sodium carbonate of brine is expressed as Total Alkalinity (TA %) of brine and as an example, calculation of total alkalinity for one of unit is explained below;

- $2NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$ [1]

Molecular weight of $NaHCO_3$ is 84 g/mol

Molecular weight of Na_2CO_3 is 106 g/mol

From equation [1] to convert sodium bicarbonate into sodium carbonate:

(Molecular weight of Na_2CO_3) / 2*(Molecular weight of $NaHCO_3$) = 106 /168 = 0.631 is used as coefficient.

For example; sodium carbonate concentration of unit PU51 is 115.6 g/l and sodium bicarbonate is 70.5 g/l given first line of Table 1. And total alkalinity (g/l) is;

TA (g/l) = 115.6 + 0.631*70.5 = **160.1 g/l**

Moreover, total alkalinity in percentage is calculated as below;

Density of brine was given as 1.16 g/cm^3 (i.e. 1,160 g/l)

TA (g/l) = 0.01 * Density of brine * TA (%) [2]

From equation [2], TA % = 160.1 / (0.01*1,160)

TA % = 13.8 %

After calculating percentage of total alkalinity for all units, 18,433 of data were collected to determine the effect of injection temperature and flow rate on TA % of brine, Table 3&4 are given as an example of first 2 months of data for unit PU51.

Table 3. Production and laboratory data of unit PU51 (first 2-month)

Time (h)	TA (%)	T (ºC)	Q (t/h)	Time (h)	TA (%)	T (ºC)	Q (t/h)
24	13.6	56	9.8	**744**	11.5	51	25.2
48	13.8	57	15.4	**768**	12.0	51	24.3
72	13.8	54	17.8	**792**	11.8	48	24.0
96	13.3	55	18.5	**816**	11.9	47	24.3
120	13.5	55	20.4	**840**	11.8	45	22.1
144	9.5	55	18.9	**864**	12.1	45	23.3
168	10.1	54	19.7	**888**	12.4	45	21.4
192	10.0	53	20.3	**912**	12.3	43	20.0
216	9.7	53	20.1	**936**	12.3	42	21.3
240	10.5	54	19.2	**960**	12.0	45	22.2
264	12.1	54	16.4	**984**	12.1	42	23.7
288	10.6	55	16.6	**1,008**	11.6	46	25.1
312	11.1	54	18.6	**1,032**	12.0	46	25.4
336	10.4	55	20.4	**1,056**	11.7	54	23.8
360	10.4	54	20.3	**1,080**	12.4	67	22.3
384	11.0	53	20.1	**1,104**	12.6	69	22.9
408	10.0	52	20.2	**1,128**	13.4	69	23.3
432	10.5	49	22.0	**1,152**	13.5	69	22.3
456	10.0	47	19.4	**1,176**	12.3	61	27.8
480	10.2	51	19.6	**1,200**	14.3	64	21.3

Table 4. Production and laboratory data of unit PU51 (first 2-month)(cont'd)

Time (h)	**TA (%)**	**T (°C)**	**Q (t/h)**	**Time (h)**	**TA (%)**	**T (°C)**	**Q (t/h)**
504	10.5	52	19.8	**1,224**	14.3	65	19.6
528	10.6	49	19.5	**1,248**	14.6	67	24.0
552	10.5	50	15.3	**1,272**	14.3	65	27.5
576	13.0	48	23.6	**1,296**	14.6	62	29.2
600	10.5	49	25.4	**1,320**	14.5	67	31.7
624	10.7	47	23.7	**1,344**	14.1	67	34.0
648	10.7	52	24.0	**1,368**	14.4	67	35.5
672	11.1	54	23.2	**1,392**	14.0	66	15.0
696	11.6	52	24.1	**1,416**	14.3	67	30.4
720	11.5	52	24.3	**1,440**	14.4	62	29.7

The study area has been working for ten years and production continues without stopping. That's why; drilling and starting operation of new units are continuing to support process plant without any interruption. But planned or unplanned events may be occurred in some periods such as power cut, changing electrical devices such as flow meter and production cut for maintenance. For this reason, there were missing data in the historical data and some of assumptions were made in this regard. These assumptions are as follows:

- All units were assumed to start the production at the same time.
- The missing rows in the historical dataset were filled with a random value in compliance with the trend of the pre- and post-data flow. By this way, potential statistical errors were avoided.
- Operation of some of units may be stopped for some reasons; at that time these off-days are neglected and production hours were shifted for these days.

4.2.1. Analysis of production units

The purpose of this thesis is to analyze injection temperature (T), injection flow rate (Q) and brine concentration (TA %) of 19 production units and verify whether the regression analysis methods would explain operational factors are affecting brine concentration increase or not. For this production data, **Multiple Regression Analysis Method** was chosen to examine the contribution of temperature and flow rate of solvent to the increase of TA %. This method was applied by using **Minitab Program**, a general-purpose statistical software package. A final analysis related to all units is generated to help observing and predicting behavior of production units to be drilled in the future. The model also shows which variables play the most important role in the increasing of brine TA %.

To better understand the maturity of production units, operational factors which are temperature and flow rate of solvent were observed depending on time. Two different time period is chosen to observe their effect on maturity of cavern. Injection temperature and flow rate effect on reaching maturity is compared and evaluated within first twelve and three months of production period.

Four units drilled from different target trona seams will be given below in detail and others are given in Appendix 1.

- **PU51**

First 12-month production data of unit PU51, drilled in U5 trona seam, was analyzed. Firstly, production data including injection temperature and flow rate of unit and laboratory data including TA % of brine were analyzed by using box-plot given in Figure 26.

Box and whisker plots provide a useful technique for describing data and they also provide graphical display of distribution of data around the median. The box shows the middle half of data. In the case that median is located in the center of box and whiskers are about the same length, data is distributed around median symmetrically. Otherwise, the data is skewed toward other end of box (Brase & Brase, 1997).

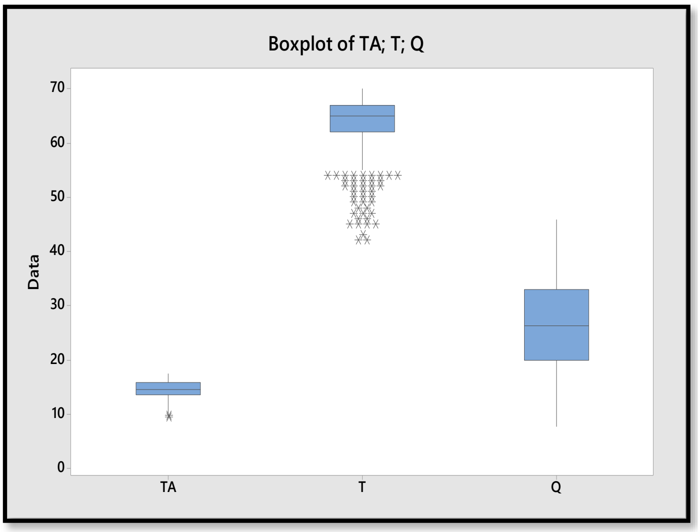

Figure 26. Box-plot of PU51 data (Minitab)

Outliers are erratic data values compared to behavior of remaining dataset and they can be seen easily from other data because of their extreme high or low values. Detection and elimination of outliers are important to prevent deviations in analysis covering unfavorable results (Gölbaşı, 2015).

It is seen that total alkalinity (TA %) and injection temperature (T) values have outliers; however, injection flow rate data are well distributed according to box and whisker plot.

Injection solvent is made up at process plant and the plant has a continuous system. It means that solvent may not be prepared with same temperature for every hour and solvent having different temperature values can be fed to mining site. Outliers (star symbols) of temperature data can be explained by operational drawbacks. On the other hand, outliers of total alkalinity variable can be clarified by mismeasurements of laboratory. Outliers of temperature were interpreted with subjectively gained experience from operational part of plant. Moreover, according to general behavior of data, TA % outliers were explained objectively. As a result, most of these data were corrected preventing disturbing distribution of data.

After controlling utility of operation data, regression model was constructed using Total Alkalinity of brine (TA %), injection temperature (T) and injection flow rate (Q) for 12-month and 3-month production data, separately.

Firstly, 12-month data of unit was added to Minitab software and time (TIME), injection temperature (T) and injection flow rate (Q) was chosen as free predictors and response of equation was total alkalinity of brine (TA). After construction of regression subsets (Figure 27), R-Squared value, a measure in statistics of how close the data are to the fitted regression line, table was obtained from data.

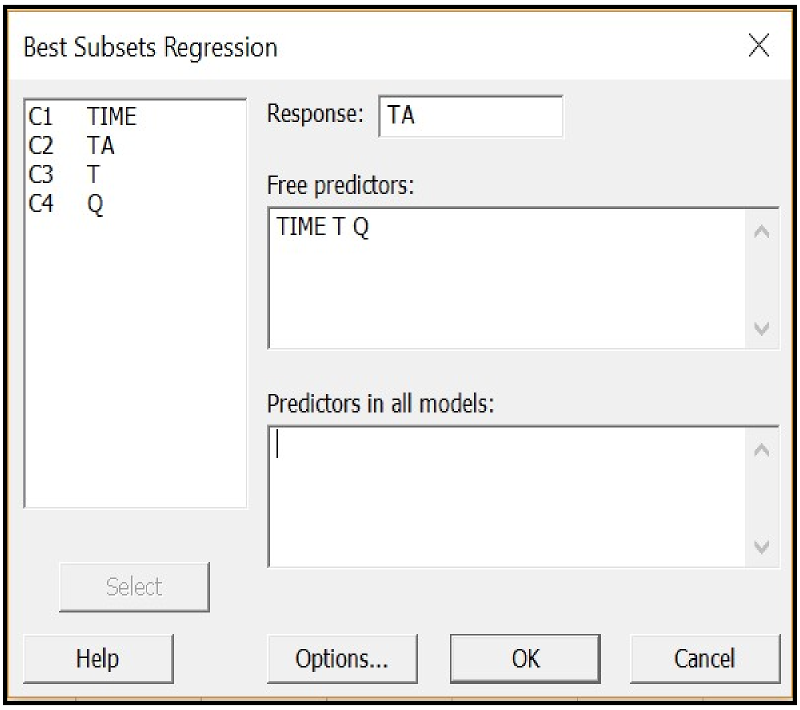

Figure 27. Regression subsets for each unit (Minitab)

A decision on which parameter should be included in a regression equation should be given by using R-Squared (adj) values since R-Squared (adj) eliminates the effect of parameter number, and removes the biased results. For this model variables were put into system in first order and after that to see whether power of variables is changing R-squared percentage or not, square of T and Q were tried. And results show that using first power of variables has higher R^2 value than second power of them (Equation 13 and 14). For this reason, first order of variables are studied.

Then, regression parameters added to system again (Figure 28) and regression model was obtained (Table 5).

Table 5. R-Squared values for PU51 with added parameters (12-month data)

Eqn	**Vars**	**R-Sq**	**R-Sq (adj)**	**TIME**	**T**	**Q**	**T^2**	**Q^2**
1	1	67.6	67.5	X				
2	1	40.6	40.5				X	
3	1	40.5	40.3		X			
4	1	9.7	9.4			X		
5	1	8.8	8.5					X
6	2	71.6	71.5	X	X			
7	2	71.5	71.4	X			X	
8	2	67.9	67.7	X		X		
9	2	67.8	67.7	X				X
10	2	51.5	51.2		X			X
11	3	71.7	71.5	X	X			X
12	3	71.7	71.5	X	X		X	
13	3	71.7	71.5	X	X	X		
14	3	71.6	71.4	X			X	X
15	3	71.6	71.3	X		X	X	
16	4	72.1	71.7	X	X	X		X
17	4	71.9	71.6	X		X	X	X
18	4	71.9	71.6	X	X		X	X
19	4	71.8	71.5	X	X	X	X	
20	4	51.9	51.3		X	X	X	X
21	5	72.1	71.7	X	X	X	X	X

According to Table 5, different variations were tried using production data;

- Equation 6 shows that when TIME and T were used to explain TA % increase, R- sq (adj) values was 71.5 %.
- Equation 8 shows that when TIME and Q were used to explain TA % increase, R- sq (adj) values was 67.7 %.
- Moreover, equation 13 gives R-sq (adj) vales as 71.5 using TIME, T and Q. It was same with equation 8.
- When equations 7, 9 and 14 were analyzed using T^2 and Q^2 as an explanation of TA % increase, R- squared (adj) values were as similar as first power of T and Q.

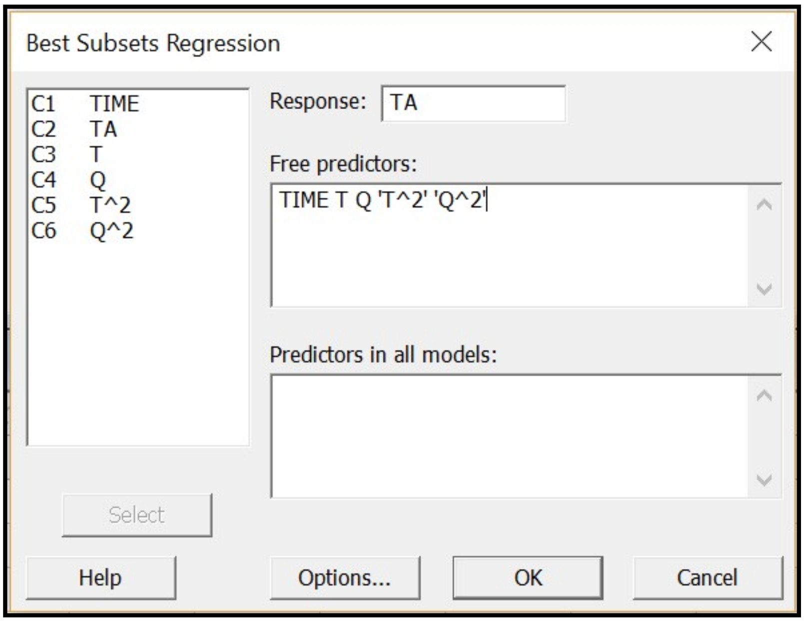

Figure 28. Regression parameters of each unit (Minitab)

When three cases; TIME, T, Q and TIME T^2, Q^2 and TIME, and also T, Q, T^2, Q^2 (Equations 13, 14 & 21) of R- squared (adj) values were examined it was seen that there was not big difference between them. That's why, for most of units, analyzing increase of TA, injection temperature (T) and injection flow rate (Q) were used in first order.

Additionally, p value is used to determine statistical significance in a hypothesis test and a measure of the strength of the evidence in collected data against null hypothesis. The smaller the p-value means that the sample evidence is stronger for rejecting null hypothesis (H_0). More specifically, the p-value is the smallest value of α that result in the rejection of H_0.

- For any value of $\alpha >$ p-value, it is failed to reject null hypothesis (H_0), and
- For any value of $\alpha \leq$ p-value, null hypothesis is rejected (Nahm, 2017).

According to p values of data given in Table 5, p value of Q is 0.402. It is higher than significance level of $\alpha = 0.05$ for 95 % confidence interval, then it is failed to reject null hypothesis. A high p value suggests that sample provides not enough evidence that the null hypothesis is rejected for the entire population.

Consequently, regression equation did not contain flow rate (Q) as a function of increasing TA % because of high p-value.

Table 6. P-values of PU51 (12-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.000
Q	0.402

Table 7. Model summary of PU51 (12-month data)

S	R-sq	R-sq (adj)	R-sq (pred)
0.948523	71.63%	71.47%	71.02%

Then, flow rate (Q) parameter was removed from dataset and p value was calculated again (Table 6). Then, Table 7 was created using TIME and T data and new R-squared (adj) value was given as 71.5 %. Regression equation was constructed:

$$\mathbf{TA = 7.744 + 0.000485\ TIME + 0.0740\ T}$$

However, it is obvious that to carry on solution mining process, some amount of solvent should be injected to underground and brine should be accumulated from underground. That's why, descriptive statistics data of injection flow rate (Q) was given in Table 8. 360 of injection flow rate data were used to construct descriptive statistics table and according to this, minimum value of Q is 7.6 and maximum value is 45.9. Also, mean of flow rate (Q) data is 26.7. Moreover, Q1 and Q3, which are time associated with the first survival probability in the table less than or equal to 0.75 and 0.25, respectively are given in Table 8. As a result, for PU51, using 12-month production data, found regression equation above was valid only for average value of Q.

Table 8. Descriptive statistics of Q (12-month data)

Variable	**N**	**Mean**	**SE Mean**	**St. Dev.**	**Min.**	**Q1**	**Median**	**Q3**	**Max.**
Q	360	26.7	0.4	7.9	7.6	19.8	26.3	33.0	45.9

Furthermore, to see the behavior of variables first months of production, first 3 month of data was analyzed for unit PU51. According to results, R-Squared (adj) was 56.1 % with using time, temperature and flow rate as a function of equation (Table 9).

Table 9. R-Squared values for PU51 (3-month data)

Vars	**R-Sq**	**R-Sq (adj)**	**TIME**	**T**	**Q**
1	50.3	49.8		X	
1	47.0	46.4	X		
2	57.5	56.5	X	X	
2	54.0	52.9		X	X
3	57.5	56.1	X	X	X

When p-values were checked, it was seen that p-value of Q is higher than 0.05 for 95 % confidence interval (Table 10). Q dataset was removed from equation. Descriptive statistics data of Q was given in Table 11 and in these intervals of Q data; regression equation was given as below for unit PU51, drilled in U5 trona seam, (first 3-month of production data):

$$\mathbf{TA=6.855 + 0.000908\ TIME + 0.0823\ T}$$

Table 10. P-values of PU51 (3-month data)

Term	P-Value
Constant	0.000
TIME	0.009
T	0.000
Q	0.747

Table 11. Descriptive statistics of Q (3-month data)

Variable	N	Mean	SE Mean	St. Dev.	Min.	Q1	Median	Q3	Max.
Q	90	25.8	0.7	6.6	9.8	20.3	24.0	31.4	45.6

- **PU69**

This unit was drilled in U6 trona seam and U6 is the most common target seam at the mine site. For this unit,

- Firstly, box-plots were drawn using injection temperature, flow rate and brine concentration (TA %). Total Alkalinity and temperature values show that there were some outliers in the plot (Figure 29). For TA values, it was explained as laboratory mistakes and starting or stopping operation of unit. Moreover, because of operational changes may be caused by outlier data of injection temperature.

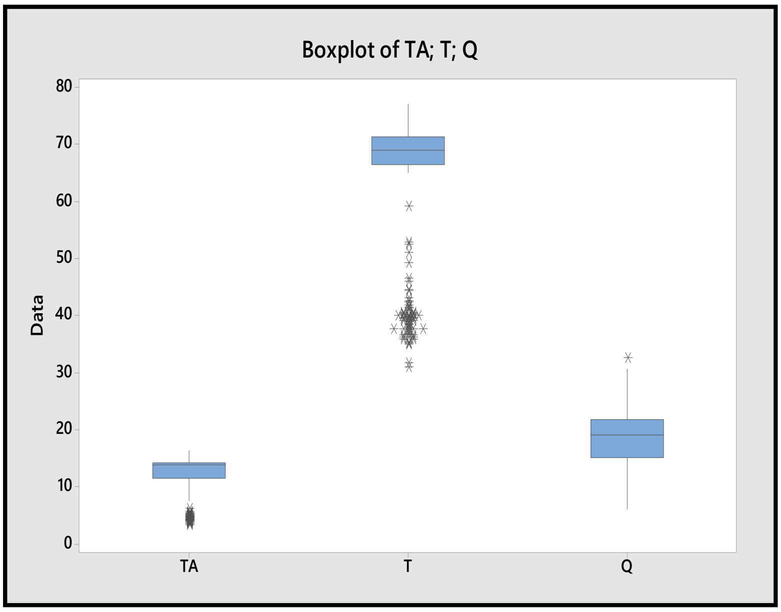

Figure 29. Box-plot of PU69 data

- Secondly, p-values were checked for 95 % confidence interval and it was seen that p-value of flow rate (Q) was bigger than 0.05 (Table 12). For this reason, parameter of Q was removed from equation and p-values were checked again (Table 13).

Table 12. P-values of PU69 (12-month data)

Term	**P-Value**
Constant	0.296
TIME	0.000
T	0.000
Q	0.099

Table 13. P-values of PU69 without flow rate parameter (12-month data)

Source	**P-Value**
Regression	0.000
TIME	0.000
T	0.000

- Then, R-squared (adj) was calculated as **74.6 %** by using first 12-month of production data (injection temperature and brine concentration) with temperature (Table 14).

Table 14. R-Squared values for PU69 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	58.0	57.9	X		
1	56.7	56.6		X	
1	28.5	28.3			X
2	74.8	74.6	X	X	
2	63.4	63.2		X	X
2	58.7	58.5	X		X
3	74.9	74.7	X	X	X

- Finally, model was summarized for unit PU69 and Total Alkalinity equation was obtained depending on time and temperature with a given range of flow rate (Table 15).

Table 15. Descriptive statistics of Q (12-month data)

Variable	N	Mean	SE Mean	St. Dev.	Min.	Q1	Median	Q3	Max
Q	360	18.4	0.2	4.6	6.0	15.1	19.0	21.7	32.5

TA = -2.211 + 0.000794 TIME + 0.1643 T

For this unit, using first 3-month of production data, R-squared was calculated but it was very close to 0 %. It is known that higher the R-squared, the better the model fits the data.

- **PL31**

Unit PL31 was drilled in L3 trona seam and first 12-month operation data were given to analyze how operational factors affect maturity of production units. According to 12-month production data, regression analyses were tried but this method did not work for this data (Table 16). R^2 (adj) is found as 25.9 and it is very low value. So, it means that 12-month data is not close to the fitted regression model and model is poor for these data.

Moreover, regression analyses was done for 3-month data of unit (Table 17) and according to higher p-values of time and flow rate given in Table 18, they should be removed from regression equation. R-squared value was found as **63.9 %.**

Table 16. R-Squared values for PL31 (12-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	18.5	18.3	15.7	38.6	0.98043		X	
1	6.5	6.3	5.1	96.7	1.0501	X		
1	0.1	0.0	0.0	127.8	1.0856			X
2	24.0	23.5	21.2	14.2	0.94840	X	X	
2	18.6	18.1	15.5	40.4	0.98159		X	X
2	12.1	11.6	9.9	71.7	1.0198	X		X
3	26.5	25.9	23.5	4.0	0.93387	X	X	X

Regression equation was obtained with only a parameter of temperature in the flow rate range of range 14.5 and 30.4 tph (Table 19).

$$\mathbf{TA = - 0.87 + 0.1978\ T}$$

Table 17. R-Squared values for PL31 (3-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	64.4	64.0	62.6	0.8	0.95395		X	
1	22.4	21.5	17.2	103.4	1.4093	X		
1	14.8	13.8	9.4	121.9	1.4764			X
2	64.7	63.9	61.6	2.1	0.95581	X	X	
2	64.6	63.8	61.4	2.3	0.95664		X	X
2	24.1	22.4	16.7	101.1	1.4012	X		X
3	64.8	63.5	60.1	4.0	0.96057	X	X	X

Table 18. P-values of PL31 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.592
T	0.000
Q	0.709

Table 19. Descriptive statistics of Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
Q	90	20.2	0.4	3.6	14.5	19.1	20.2	20.8	30.4

- **PL63**

This unit was drilled in L6 trona seam and 12 and 3 months of production data also analyzed for this unit. Box-plot of data was given below Figure 30. It shows that TA values were well distributed, although flow rate data had some outliers and temperature data was lower quartile. Since the injection temperature and flow rate are operation parameters, it is normal to have outliers and non-distributed values.

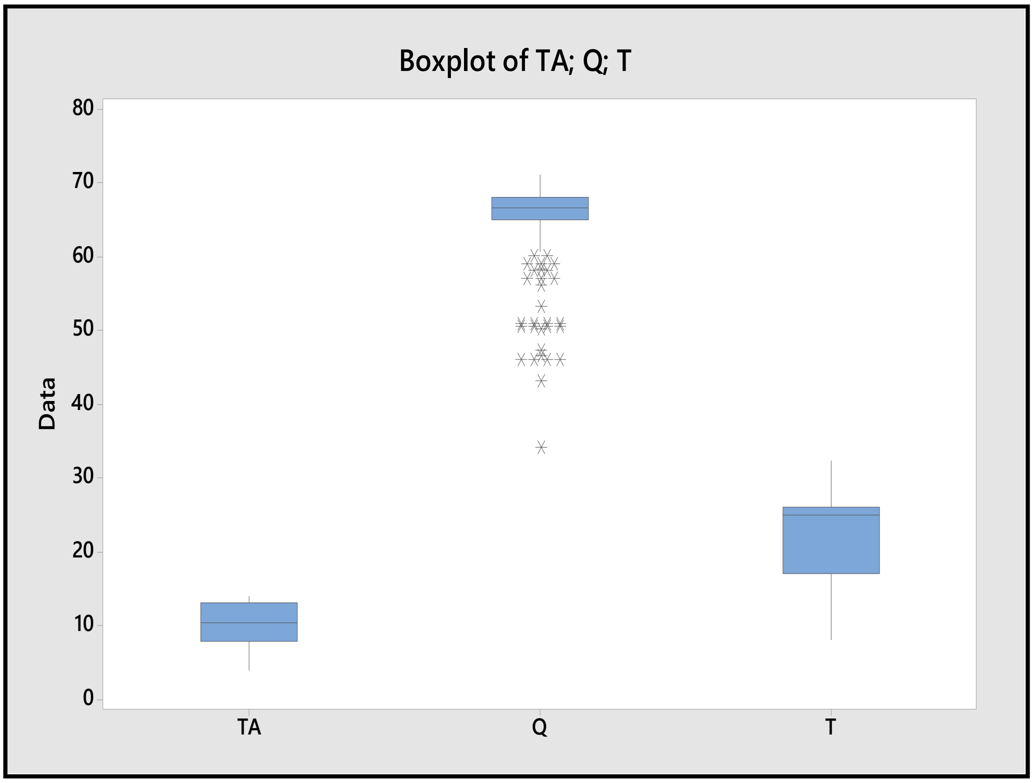

Figure 30. Box-plot of PL63 data

After checking distribution of production data, R-squared (adj) was calculated as **70.6 %** (Table 20) and according Table 21 given below shows that p-values of temperature is bigger than 0.05. For this reason, temperature parameter was emitted from regression equation and mean of temperature was given as 65.8 ^{o}C in 12-month production period (Table 22).

Then, model was finalized and regression equation of PL63 was obtained**:**

TA=6.856 + 0.000989 TIME – 0.0466 Q (with a 65.8 ^{o}C average T)

Table 20. R-Squared values for PL63 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	70.5	70.5	X		
1	20.3	20.1			X
1	3.3	3.0		X	
2	70.7	70.6	X		X
2	70.6	70.5	X	X	
2	23.5	23.1		X	X
3	70.8	70.5	X	X	X

Table 21. P-values of PL63 (12-month data)

Source	p-Value (before)	Source	p-Value (after remaining T)
Regression	0.000	Regression	0.000
TIME	0.000	TIME	0.000
T	**0.419**	**T**	**-**
Q	0.013	Q	0.010

Table 22. Descriptive statistics of T (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
T	360	65.8	0.26	4.8	34.0	65.0	67.0	68.6	71.1

For this unit, regression analysis method was tried also first 3 months of production data but its results are not applicable because of low R^2 (adj) value.

4.2.2. Analysis of U6 trona seam

Most of production units are drilled in U6 trona seam at the study area. 12 out of 19 selected units were also units drilled in this seam. In addition to analyzing production units separately, U6 trona seam was analyzed because of its common distribution in the mining site.

To see operational factors affecting maturity of units and estimating maturity time of U6 trona seam, regression analysis was carried out and R^2 (adj) values found as 31.8 % using 6 of production units' 12-month data drilled in U6 trona seam (Table 23).

P-values of data are lower than 0.05 (Table 24). For this reason, regression equation consists of parameters of TIME, TA and Q with a given statistical data (Table 25). Regression equation for U6 trona seam is given below:

$$\mathbf{TA = 2.072 + 0.000604\ TIME + 0.13225\ T - 0.01709\ Q}$$

Table 23. R-Squared values for U6 seam (12-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	22.6	22.5	22.4	273.3	2.7280	X		
1	8.8	8.8	8.6	677.7	2.9601		X	
2	31.7	31.7	31.5	5.7	2.5623	X	X	
2	22.8	22.7	22.5	268.8	2.7248	X		X
3	31.9	31.8	31.5	4.0	2.5605	X	X	X

Table 24. P-values of U6 seam (12-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.000
Q	0.053

Table 25. Descriptive statistics of U6 seam (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min	Q1	Medi an	Q3	Max
TA	2010	12.9	0.07	3.1	1.6	12.6	14.0	14.9	17.8
T	2010	65.7	0.16	7.1	30.8	64.0	68.0	70.0	79.0
Q	2010	19.9	0.15	6.5	0.0	15.1	19.1	22.1	45.9

4.2.3. Results and evaluation of production units

At the study area, 19 production units were selected from one part of mining site. These production units were drilled four different trona seams which are U5, U6, L3 and L6. Production data of these units were accumulated and injection temperature and injection flow rate were determined as operational factors.

Multiple regression analysis was done using production data of 19 units separately to see whether injection temperature, flow rate and time affects brine concentration (TA %) or not. According to data and results obtained by Minitab software (Table 26);

- Out of 19 units; relation between injection temperature and flow rate with increase in brine concentration would be explained by 10 units using 12-month production data. Other 9 units failed to be explained by a regression equation with a sufficient R^2 value. The reasons for low R^2 value will be discussed later on.
- Out of 19 units; relation between injection temperature and flow rate with increase in brine concentration would be explained by 14 units using 3-month production data.

Table 26. Summary of the regression equations for the units

Units	Seam	Data Used (mon)	R^2 (adj)	Regression Equation	Data Used (mon)	R^2 (adj)	Regression Equation
PU51	U5	12	71.5	TA = 7.744 + 0.000485 TIME + 0.0740 T	3	56.5	TA=6.855 + 0.000908 TIME + 0.0823 T
PU52	U5	10	-	-	3	38.5	TA= 7.83 + 0.000962 TIME + 0.0706 T
PU61	U6	6	-	-	3	56.5	TA=11.477 + 0.000837 TIME + 0.0625 Q
PU62	U6	7	74.6	TA=12.155 + 0.000948 TIME – 0.02352 Q	3	64.8	TA = 10.997 + 0.001643 TIME
PU63	U6	12	75.0	TA=-6.90 + 0.001409 TIME + 0.0872 T + 0.3831 Q	3	45.3	TA = 3.183 + 0.002944 TIME
PU64	U6	10	-	-	3	72.8	TA=13.81 + 0.001855 TIME – 0.0589 T + 0.0459 Q
PU65	U6	12	-	-	3	58	TA = 11.004 + 0.002450 TIME
PU66	U6	12	-	-	3	75.8	TA = 21.60 + 0.002465 TIME – 0.1577 T
PU67	U6	12	31.9	TA = 4.61 + 0.000404 TIME + 0.1594 T - 0.1741 Q	3	65.6	TA=-9.4 + 0.003862 TIME + 0.340 T – 0.2947 Q
PU68	U6	12	-	-	3	62.9	TA=34.9 + 0.003837 TIME – 0.491 T + 0.3343 Q
PU69	U6	12	74.6	TA = -2.211 + 0.000794 TIME + 0.1643 T	3	-	-
PU610	U6	12	49.0	TA = 16.473 - 0.000148 TIME - 0.07146 Q	3	35	TA = 15.422 + 0.000399 TIME – 0.0512 Q
PU611	U6	12	48.7	TA = 9.136 + 0.000852 TIME – 0.0949 Q	3	-	-
PU612	U6	11	-	-	3	74.8	TA = 14.67 + 0.002311 TIME – 0.2632 Q
PL31	L3	12	-	-	3	63.9	TA = -0.87 + 0.1978 T
PL61	L6	7	41.9	TA = 9.225 + 0.000353 TIME + 0.0935 Q	3	-	-
PL62	L6	12	-	-	3	34.3	TA = 11.354 + 0.000957 TIME
PL63	L6	12	70.6	TA=6.856 + 0.000989 TIME – 0.0466 Q	3	-	-
PL64	L6	12	49.5	TA = 10.6342 + 0.000344 TIME	3	-	-

- Average of R-Squared (adj) for 12-month production data was 58.7 % and for 3-month was 57.5 %. The 3-month data was observed whether there was any difference between first months and other part of production period. However, it was seen that their results were very close to each other.
- In addition to checking the correlations for the units individually, the data was also evaluated for different trona seams where multiple or single unit may be operated;

U5 Trona Seam: Two units (PU51 and PU52) were chosen from U5 trona seam. Both of R-Squared (adj) value of these units was acceptable for 3 month data but one of them could be explained for 12 month data with statistically important R-squared values.

U6 Trona Seam: Twelve units (PU61, PU62, PU63, PU64, PU65, PU66, PU67, PU68, PU69, PU610, PU611 and PU612) were chosen from U6 trona seam. 10 of them for using 3-month data and 6 of them using 12-month data was explained by injection temperature and flow rate affects brine concentration.

Since there are many uncertainty coming from geology of mine, design of mine and drilling operations, 6 out of 12 units in U6 trona seam were selected to be evaluated in regression analysis due to their sufficient and clearly-understanding datasets where the uncertainties are relatively low compared to the remaining units. Briefly, operations were observed to be performed in more convenient working conditions in these 6 units.

Brine concentration, injection temperature and flow rate of 6 units' data is given in Figure 31, 32 and 33. According to Figure 31, it is seen that TA % increases suddenly and when cavern reaches maturity level, TA % values continues almost stable. According to this figure, production units drilled in U6 trona seam may reach maturity level in minimum 2,000 hours and maximum 3,000 hours. Based on this maturity duration, it may be considered as a production unit will be acceptable for processing plant 2,000-3,000 hours after starting production.

At the study area, soda ash and sodium bicarbonate production must be continued without any interruption. Drilling schedule for production units should be prepared early since reaching maturity level takes time for units. One of the aim of this thesis is estimating maturity time of unit. It will be helpful for company to program drilling of units and they may be scheduled considering maturity period for long time production planning.

Moreover, brine concentration increase depends on temperature rather than injection flow rate according to Figure 31 and 32.

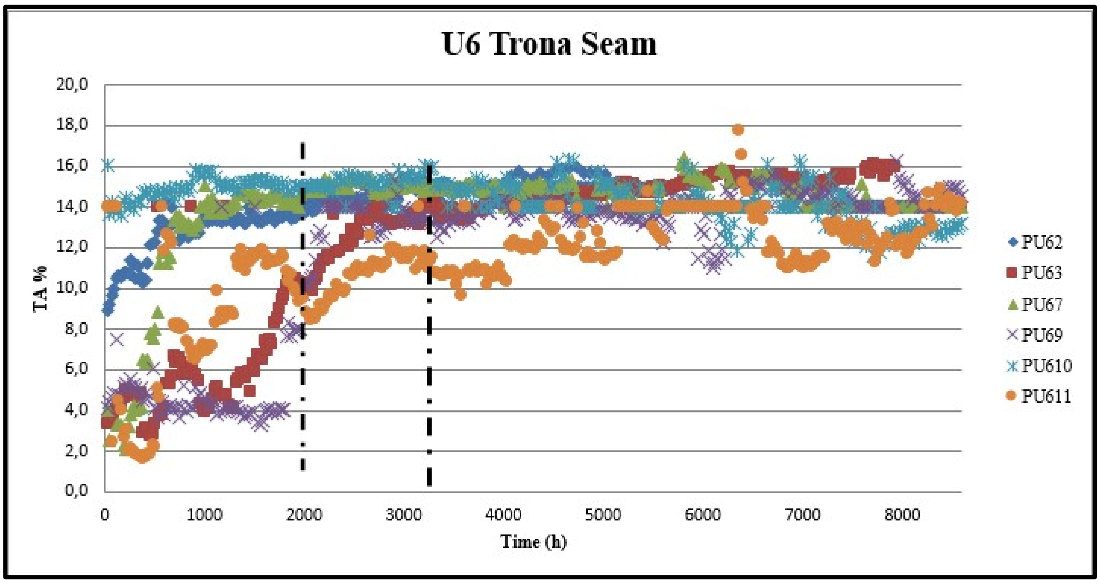

Figure 31. U6 trona seam TA % vs. time

<u>L3 Trona Seam</u>: One unit (PL31) was chosen from L3 trona seam. This unit had 64 % R-squared (adj) value for 3 month data.

<u>L6 Trona Seam</u>: Four units (PL61, PL62, PL63 and PL64) were chosen from L6 trona seam. 3 of units had high R-squared value for 12 month data and only one of them had bigger than 30 % R-squared value with 3 month production data.

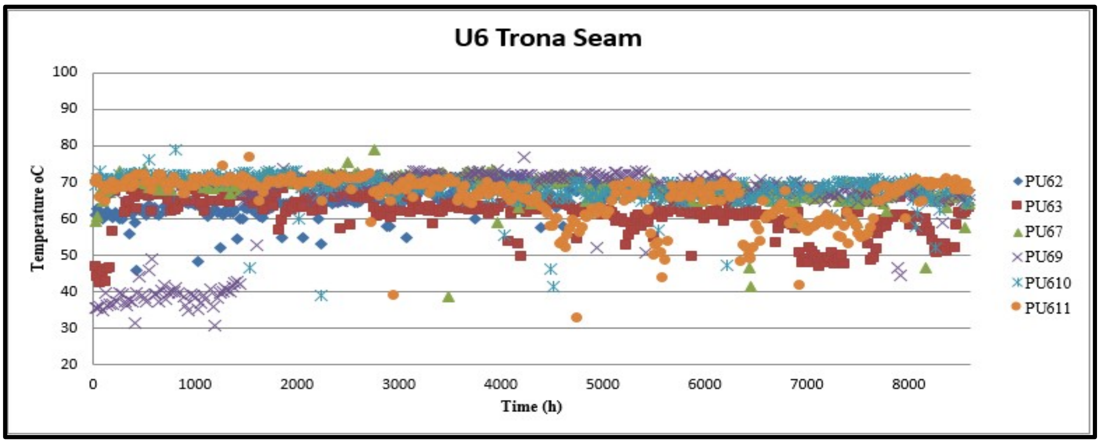

Figure 32. U6 trona seam Temperature vs. time

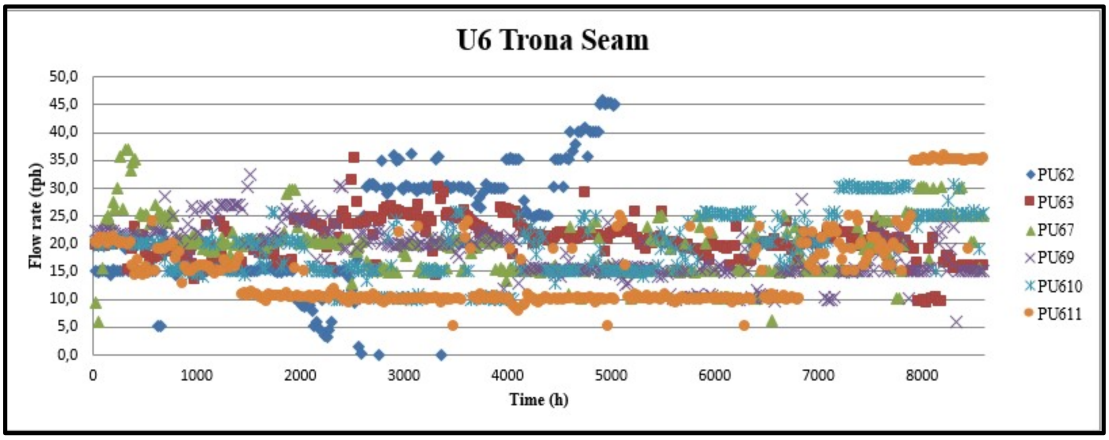

Figure 33. U6 trona seam Flow rate vs. time

In this study, it was observed that how operational quantative factors (injection temperature and flow rate), which are countable factors, affects the maturity level of the units and the possibility of estimating maturity time by using past production data. Since each production unit had a different characteristic, analyzing factors were not easy for such a complex and complicated mining area. There were a lot of external factors related to geology of mine, design and drilling part affecting maturity time level of unit. Potential effects of these factors were explained as follows:

Geology of mine: There are 12 economically extractable trona seams at the mine site. However, discontinuity of these seams may be seen at the boundary parts of site. Then, this discontinuity may affect drilling. In the case that drilling does not follow trona seam, maturity time of unit may show a variation.

Furthermore, brine concentration increase is influenced by seam thickness, grade and inclination of seam. Target trona seams are commonly U5, U6, L3 and L6 at study area. Their thickness and grade is varied in some parts of mine. And also, trona solubility rate is different in horizontal and vertical direction. According to tests conducted to find solubility rate of trona, it was seen that vertical leaching of trona was 4.74, 4.70 and 4.45 mm/h at the temperature 22, 40 and 60 ºC, respectively. At the same temperatures, horizontal leaching was 2.40, 2.49 and 2.53 (Saygun, 2008). That's why; maturity level of unit may be affected from thickness of seam. If seam is thin, trona dissolves easily in horizontal direction and it meets with non-trona zone and increase in TA % may be very slow.

Moreover, there are fold and fault systems in the mining site. These fracture and cracks may affect drilling performance of units and cavern development directly is affected from these geological formations.

Design of mine: As it were explained previous chapters, production units consist of one directional drilled and two vertical wells. At the some part of mine, design of unit can be changed for some reasons. Some of the units constructed with three vertical wells and one horizontal well or some of the units may be drilled as one vertical and one horizontal well because of limited owned land by company. Distance between well is related to retention time of solvent staying underground. Increasing brine concentration is obviously related to retention time.

Driling of units: Directional drilling is one of the special techniques used in mining area. Experience was gained about directional drilling in study area with trial and error. For this reason, there are still a number of mistakes are made. Following trona seams almost 150-200 m while drilling is not an easy work and some of drilling inside trona seam performance is low because of discontinuity of trona seam and drilling mistakes (wrong calculation, targeting wrong point etc.). Another problem arising from drilling part is passing one vertical well. While intersecting horizontal well to first vertical well, drilling path can be deviated and second vertical well can be targeted. In such cases, it is expected that first vertical target well is connected to drilling path or cavern by itself. This procedure may take some time and brine concentration increase may affect from this case.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Solution mining method is used for extracting trona ore from underground at the Beypazarı trona mine. Two vertical and one directionally drilled well are combined in a target trona seam as a production unit for solution mining. Solvent containing 2-3 % Total Alkalinity (TA) at a temperature between 60-80 ºC is prepared as injection solvent and it is injected from horizontal well and brine is taken from vertical wells with 14-15 % TA with a temperature of 40-50 ºC.

It is known that reaching production units to 14-15 % Total Alkalinity brine concentration level takes time. When units reach this brine design parameters, production unit is called as mature unit. There are a lot of units at the study area and each of them has their own characteristics while reaching maturity level.

There are some operational factors affecting maturity of production units. In this thesis, injection temperature and injection flow rate is observed as operational factors of production units depending on time. Nineteen (19) units were chosen from mining area drilled in different trona seams (U5, U6, L3 and L6) to see how operational factors affect increasing brine concentration and whether it is possible to estimate maturity time for U6 trona seam or not. Using statistical software Minitab program, regression analysis is done for units, separately and also combining units drilled in U6 trona seam.

According to multiple analysis results; 10 of 19 units was explained by effect of injection temperature and flow rate on increasing brine concentration depending on time with R^2 is 58.7 %. And also, 14 of 19 units have an average R^2 is 57.5 %. It was seen that injection temperature and flow rate affects brine concentration but regression equations were examined in detail it was seen that some of the equations did not contain all parameters at the same time. Moreover, when 3-month R-squared value and 12-month was compared, there was no big difference between first months of brine production and long period of brine production.

Furthermore, when results were observed in the basis of trona seams; 2 units drilled in U5 trona seam and out of 2 units, for 12 month production their average R^2 value is 71.5 %. 1 unit drilled in L3 trona seam has R^2 value is 63.9 %. Then, 4 units were chosen from L6 trona seam. 3 of 4 units were explained by 54.0 % R^2 value.

The most common trona seam is U6 in the study area. For this reason, it is important that to see how operation factors affect maturity level of units in this trona seam. 6 of the units drilled in U6 seam were combined and regression analysis was done. According to results of U6 seam; injection temperature and flow rate effect on brine concentration depending on time was explained 31.8 % with and equation of $TA = 2.072 + 0.000604\,TIME + 0.13225\,T - 0.01709\,Q$. With this equation using operational factors, time when unit reaches maturity level may be estimated in almost 32 % R^2 (adj) value.

In this study, it was observed that how operational quantative factors (injection temperature and flow rate), which are countable factors, affects the maturity level of the units and the possibility of estimating maturity time by using past production data. Since each production unit had a different characteristic, analyzing factors were not easy for such a complex and complicated mining area.

There were a lot of external factors related to geology of mine, design and drilling part affecting maturity time level of unit. Geology of mine may change at the boundary part of mine and discontinuities of trona seam may be seen and the drilling pipes may not be follow trona seam and it affects maturity time of units. Seam thickness, grade and inclination of seam may affect brine concentration of production units. Folding and faults systems also may affect production period of units.

Moreover, changing design of unit, changing number of vertical wells in production unit because of surface settlements and distance between vertical wells affects reaching maturity level of production units.

Furthermore, last external factor is drilling performance of horizontal wells. It is known that it was not easy to connect well underground. Some of time, because of discontinuity of trona and wrong calculation, horizontal well can pass vertical wells or its target point in the trona is wrong. In this case, reaching maturity takes some time.

Injection temperature and flow rate affects increasing brine concentration as operation factors depending on time. By the help of external factors, results are supported and improved. It is suggested that decreasing parameters of external factors, it is easier to understand and see how operational factors affecting maturity of production units and estimation of new drilled units maturity time.

Although there are a lot of external factors while completion of production units, the company should reach production goals with yearly planned units. Approximately 50 units are operating at the same time and at least 5-10 units are remained as stand-by position and these units should be mature to feed process plant. The aim of this thesis is to find how operational factors affecting reaching maturity level and to estimate the maturity level of production units drilled in different seams but especially drilled in U6 seam (common seam at the study area). Herewith, the statistical results of U6 seam will be helpful for preparing daily operation, short term or long term mine plan. With the light of the statistical data obtained by seam U6, production units drilled in U6 trona seam may reach maturity level 2,000-3,000 hours after started production. Drilling schedule for mine plan can be made up according to this results.

Other operational factors such as injection pressure may be searched and observed number of production units may be increased to get more precise result related to reaching maturity level. According to these results, data may be examined in detail.

REFERENCES

Beşir, T., & Kafadar, S. M. (2018). Developments in Planning and Production Steps of Solution Mining in Beypazarı Trona Field. *International Mineral Processing Symposium.* Antalya.

Bolen, W. P. (2017). *Mineral Commodity Summaries.* United States Geological Survey.

Brase, C. H., & Brase, C. P. (1997). Averages and Variation. *Understanding Basic Statistics* (p. 125).

CdFI, MDPA, Sofremines, & Teknomad. (1991). *Etibank Beypazarı Trona Underground Mining Project, Deposit Evaluation Report.* Ankara.

Gölbaşı, O. (2015, September). Reliability-Based Maintenance Optimization of Walking Draglines. 64. Ankara, Middle East Technical University, Ankara: Middle East Technical University.

İnceefe, Ö., & Çakmakçı, G. (2002). beypazarı Trona Projesi Fizibilite Raporu . *Cilt 1- Jeolojik ve Jeomorfolojik, Jeokimyasal, Jeoteknik ve Jeoistatistiksel Çalışmalar*. Beypazarı: Park Teknik A.Ş.

Mineral Commodity Summaries 2018. (2018). 152-154.

Nahm, F. S. (2017, September 27). What the P values really tell us. *Korean Journal of Pain* , 241-242.

Okay, A. I. (2008). Geology of Turkey: A Synopsis. *Anschnitt 21* (s. 19-42). içinde

Okay, A. I. (2011). Tavşanlı Zone: The Northern Subducted Margin of the Anatolide-Tauride Block. *Bulletin of Mineral Reaserch and Exploration* , 191-221.

Onargan, T., & Helvacı, C. (2001). Ankara-Beypazarı Doğal Soda (Trona) Sahasının Önemi ve İşletme Parametrelerinin İrdelenmesi. *4. Endüstriyel Hammadeler Sempozyumu* . İzmir.

Örgül, S. (2003, August). *Evaluation of Soda Ash Production Parameters from Beypazarı Trona Ore.* Ankara: Middle East Technical University.

Özgüm, C., Gökmenoğlu, O., & Erduran, B. (2003). Ankara Beypazarı Doğal Soda (Trona) Sahası İzotop Hidrolojisi Çalışmaları. *Jeoloji Mühendisleri Dergisi*.

Roger L. Day, J. A. (2006). *United States Patent No. US2006/0039842A1.*

Saygılı, G. N. (2003). Effect of temperature on dissolution of Turkish trona.

Saygılı, G. N., & Okutan, H. (1995). Application of the solution mining process to the Turkish trona deposit.

Saygılı, G. N., & Okutan, H. (2005). Mechanism of the dissolution of Turkish trona.

Saygun, İ. T. (2008, March). *Computer Modeling of The Inıtial Cavern For Cavern For Beypazarı Trona Ore On The Basis of Leaching Rates, Insoluble Contents and Thickness of Trona Layer.* Middle East Technical University .

(n.d.). Retrieved September 4, 2018 from Trona: *https://www.greatmining.com/trona.html*

(n.d.). Retrieved February 25, 2018 from *http://www.greatmining.com/mining_images/trona1.png.*

(n.d.). *Wireless Measurement While Drilling.* Retrieved February 13, 2018 from Huanding Energy Services: http://www.huanding.com/en/Products_Mes.aspx?type=4&Id=31

APPENDICES

A. Regression Analyses of Production Units

- **PU52**

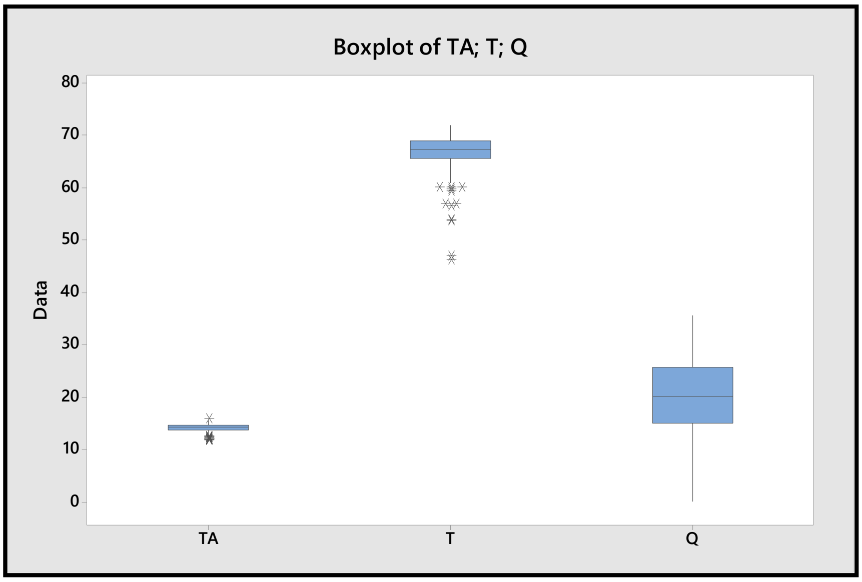

Figure A 1. Box-plot of PU52 data

Table A 1. R-Squared values for PU52 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	37.4	36.7	X		
1	1.4	0.3		X	
2	39.9	38.5	X	X	
2	38.3	36.9	X		X
3	41.6	39.6	X	X	X

Table A 2. R-Squared values for PU52 (10-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	3.4	3.0	X				
1	2.0	1.6					X
1	1.0	0.7			X		
1	0.4	0.0				X	
1	0.2	0.0		X			
2	5.9	5.2			X		X
2	3.5	2.7	X		X		
2	3.4	2.7	X			X	
2	3.4	2.7	X	X			
2	3.4	2.7	X				X
3	6.4	5.4			X	X	X
3	6.4	5.3	X		X		X
3	6.3	5.2		X	X		X
3	5.2	4.2	X	X		X	
3	4.9	3.9		X		X	X
4	9.1	7.8		X	X	X	X
4	6.6	5.3	X		X	X	X
4	6.5	5.2	X	X	X		X
4	5.4	4.0	X	X		X	X
4	5.2	3.8	X	X	X	X	
5	9.1	7.4	X	X	X	X	X

*There is no regression equation for PU52 for 10-month data

Table A 3. P-values of PU52 (3-month data)

Source	P-Value	Source	P-Value
Regression	0.000	**Regression**	0.000
TIME	0.000	**TIME**	0.000
T	0.031	**T**	0.061
Q	0.118	**Q**	-

Table A 4. Model summary of PU52 (3-month data)

S	R-sq	R-sq(adj)	R-sq (pred)
0.689189	39.90%	38.52%	35.32%

Table A 5. Descriptive statistics of PU52 (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min	Q1	Median	Q3	Max
Q	90	15.9	0.4	3.7	0.0	15.0	15.2	15.7	25.3

Regression Eqn of PU52 (3 months data): ***TA= 7.83 + 0.000962 TIME + 0.0706 T***

- **PU61**

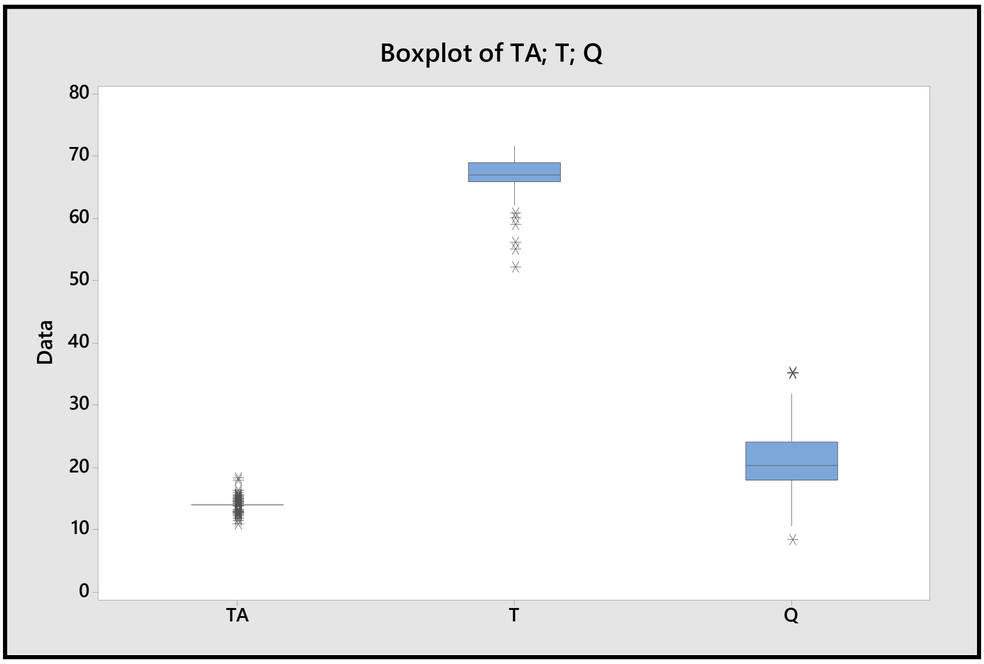

Figure A 2. Box-plot of PU61 data

Table A 6. Model Summary of PU61 (6-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.693531	28.67%	27.46%	24.57%

*There is no regression equation for PU52 for 6-month data.

Table A 7. R-Squared values for PU61 (6-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	27.3	26.9	X				
1	2.0	1.5					X
1	1.5	1.0			X		
1	0.3	0.0		X			
1	0.3	0.0				X	
2	28.5	27.7	X			X	
2	28.4	27.6	X	X			
2	27.7	26.8	X		X		
2	27.6	26.8	X				X
2	3.0	1.9			X		X
3	28.7	27.5	X			X	X
3	28.7	27.5	X		X	X	
3	28.7	27.5	X	X			X
3	28.7	27.5	X	X	X		
3	28.5	27.3	X	X		X	
4	28.8	27.1	X	X		X	X
4	28.8	27.1	X	X	X	X	
4	28.7	27.1	X		X	X	X
4	28.7	27.1	X	X	X		X
4	3.8	1.6		X	X	X	X
5	28.8	26.7	X	X	X	X	X

Table A 8. Model Summary of PU61 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.521451	57.43%	56.45%	54.43%

Table A 9. R-Squared values for PU61 (3-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	49.4	48.8	46.5	20.2	0.56530	X		
1	14.1	13.1	10.0	94.4	0.73667			X
1	9.9	8.9	6.3	103.2	0.75433		X	
2	57.4	56.4	54.4	5.4	0.52145	X		X
2	51.6	50.5	48.0	17.6	0.55610	X	X	
2	21.7	19.9	15.9	80.4	0.70724		X	X
3	59.0	57.6	54.9	4.0	0.51449	X	X	X

Table A 10. P-values of PU61 (3-month data)

Source	P-Value	Source	P-Value
Regression	0.000	Regression	0.000
TIME	0.000	TIME	0.000
T	0.070	T	0.000
Q	0.000	Q	-

Regression Eqn of PU61 (3 months data): TA=11.477 + 0.000837 TIME + 0.0625 Q

Table A 11. Descriptive statistics of T (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min	Q1	Median	Q3	Max
T	90	67.3	0.3	3.5	55.0	65.9	67.8	69.7	71.6

- **PU62**

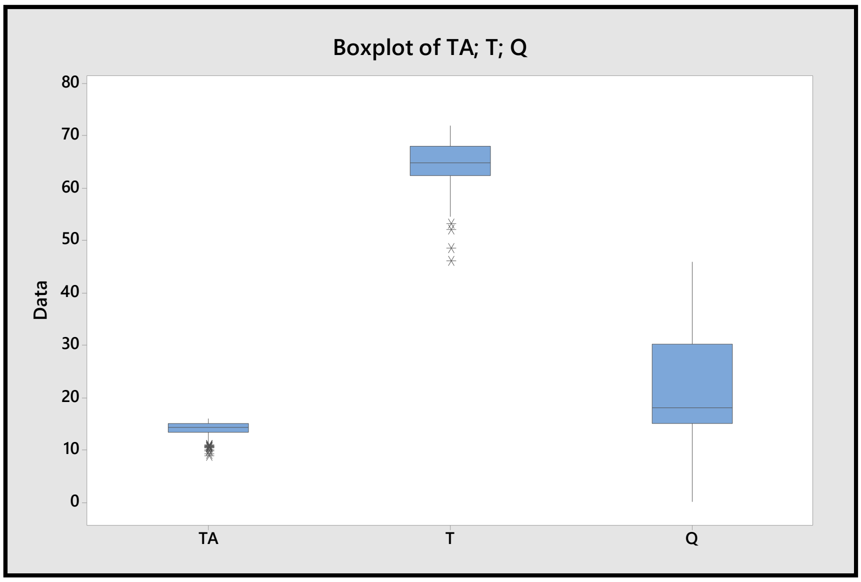

Figure A 3. Box-plot of PU62 data

Table A 12. R-Squared values for PU62 (7-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	73.4	73.3	72.6	11.6	0.72048	X		
1	32.3	32.0	31.1	347.6	1.1491			X
1	27.3	27.0	25.6	388.9	1.1912		X	
2	74.8	74.6	73.8	2.2	0.70302	X		X
2	73.4	73.2	72.4	13.5	0.72199	X	X	
2	40.8	40.2	39.0	280.3	1.0773		X	X
3	74.8	74.5	73.6	4.0	0.70436	X	X	X

Table A 13. Model Summary of PU62 (7-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.703023	74.80%	74.55%	73.84%

Table A 14. P-values of PU62 (7-month data)

Source	P-Value
Regression	0.000
TIME	0.000
Q	0.001

Regression Eqn of PU62 (7 months data): TA=12.155 + 0.000948 TIME – 0.02352 Q

Table A 15. R-Squared values for PU62 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	65.1	64.7	X		
1	5.6	4.5			X
2	65.5	64.7	X	X	
2	65.5	64.7	X		X
3	65.9	64.7	X	X	X

Table A 16. Model Summary of PU62 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.75827	65.94%	64.75%	60.56%

Table A 17. P-values of PU62 (3-month data)

Source	P-Value
Regression	0,000
TIME	0,000
Q	0,323

Regression Eqn of PU62 (3 months data): TA = 10.528 + 0.001693 TIME + 0.0285 Q

- **PU63**

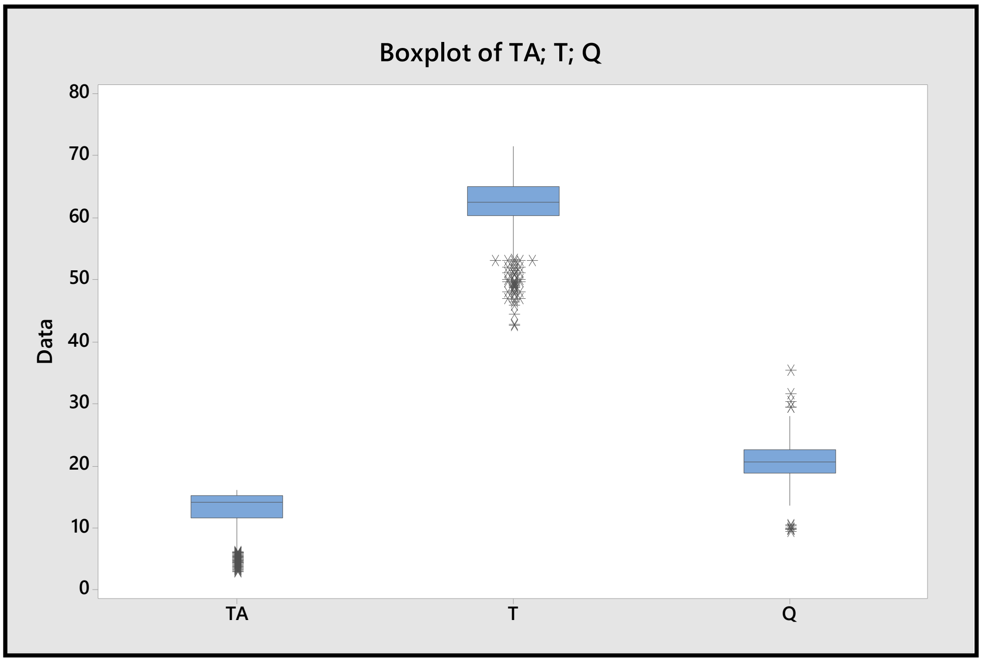

Figure A 4. Box-plot of PU63 data

Table A 18. R-Squared values for PU63 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	62.7	62.5	X		
1	6.6	6.4		X	
1	2.9	2.6			X
2	73.9	73.8	X		X
2	63.5	63.3	X	X	
2	9.8	9.3		X	X
3	75.2	75.0	X	X	X

Table A 19. Model Summary of PU63 (12-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
192.194	75.20%	75.00%	74.58%

Table A 20. P-values of PU63 (12-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.000
Q	0.000

Table A 21. Descriptive statistics of TA, T and Q (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min	Q1	Median	Q3	Max
TA	360	12.5	0.2	3.8	2.8	11.5	14.0	15.1	16.1
T	360	61.6	0.3	5.5	42.5	60.4	62.5	65.0	71.5
Q	360	20.6	0.2	3.5	9.4	18.7	20.6	22.5	35.4

Regression Eqn of PU63 (12 months data): TA=-6.90 + 0.001409 TIME + 0.0872 T + 0.3831 Q

Table A 22. R-Squared values for PU63 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	45.9	45.3	X		
1	3.0	1.9		X	
1	1.2	0.1			X
2	46.3	45.1	X	X	
2	46.0	44.7	X		X
2	4.7	2.5		X	X
3	46.4	44.5	X	X	X

Table A 23. Model Summary of PU63 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
2.01407	45.94%	45.32%	44.08%

Table A 24. P-values of PU63 (3 months data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.410
Q	0.763

Table A 25. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min	Q1	Med.	Q3	Max
TA	90	6.4	0.3	2.7	2.8	4.3	5.7	8.4	14.0
T	90	64.0	0.7	6.2	42.5	63.3	65.3	67.7	71.5
Q	90	19.2	0.3	2.6	13.5	17.0	18.9	20.8	24.6

Regression Eqn of PU63 (3 months data): TA = 3,183 + 0,002944 TIME

- **PU64**

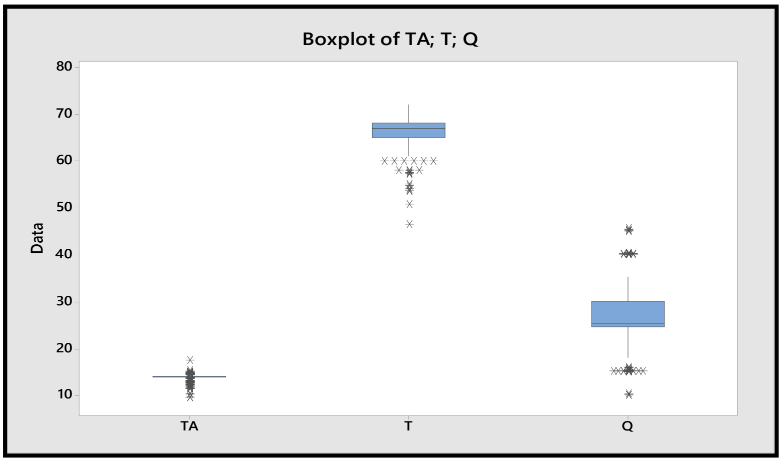

Figure A 5. Box-plot of PU64 data

Table A 26. R-Squared values for PU64 (10-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	17.4	17.1	X				
1	9.0	8.7				X	
1	8.8	8.5		X			
1	2.6	2.3					X
1	2.6	2.3			X		
2	23.8	23.3	X		X		
2	22.9	22.4	X				X
2	21.9	21.4	X			X	
2	21.6	21.1	X	X			
2	10.6	10.0				X	X
3	26.6	25.9	X		X	X	
3	26.4	25.6	X	X	X		
3	26.1	25.3	X			X	X
3	25.8	25.0	X	X			X
3	24.3	23.6	X		X		X
4	28.2	27.3	X	X	X	X	
4	27.6	26.7	X	X		X	X
4	26.8	25.8	X		X	X	X
4	26.6	25.6	X	X	X		X
4	11.3	10.1		X	X	X	X
5	28.5	27.3	X	X	X	X	X

*First 10 months data had very low R-squared value

Table A 27. R-Squared values for PU64 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	70.7	70.3	X				
1	31.2	30.4					X
1	28.5	27.7			X		
1	10.3	9.3				X	
1	9.1	8.1		X			
2	72.5	71.9	X	X			
2	72.2	71.6	X			X	
2	71.3	70.6	X				X
2	71.2	70.5	X		X		
2	37.8	36.4			X		X
3	75.9	75.0	X	X		X	
3	73.9	73.0	X	X			X
3	73.7	72.8	X	X	X		
3	73.5	72.6	X			X	X
3	73.4	72.5	X		X	X	
4	76.7	75.6	X	X		X	X
4	76.6	75.5	X	X	X	X	
4	74.1	72.9	X	X	X		X
4	73.8	72.6	X		X	X	X
4	41.7	38.9		X	X	X	X
5	76.7	75.3	X	X	X	X	X

Table A 28. P-values of PU64 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.005
Q	0.051

Table A 29. Model Summary of PU64 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.706181	73.74%	72.82%	68.48%

Table A 30. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	13.3	0.1	1.4	9.5	12.5	13.2	14.4	15.3
T	90	64.7	0.5	4.4	46.5	63.4	65.9	67.8	70.1
Q	90	27.4	0.4	4.0	15.0	25.0	30.0	30.2	31.0

Regression Eqn of PU64 (3 months data): TA=13.81 + 0.001855 TIME – 0.0589 T + 0.0459 Q

- **PU65**

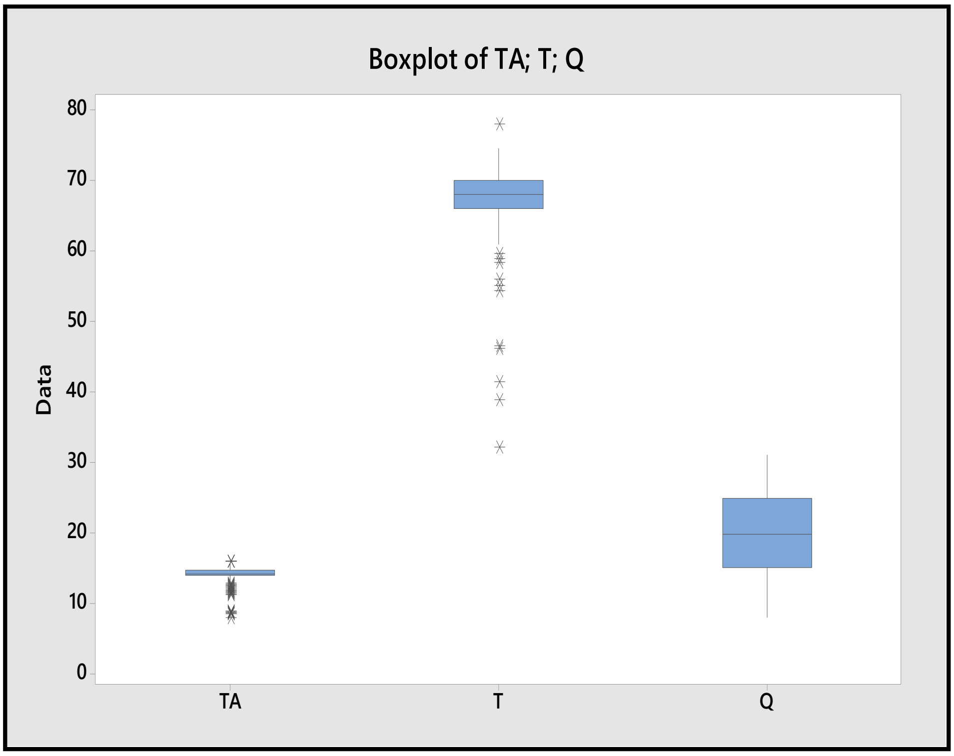

Figure A 6. Box-plot of PU65 data

*First 12-month data had very low R-squared value

Table A 31. R-Squared values for PU65 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	58.4	58.0	X		
1	21.3	20.4			X
1	3.3	2.2		X	
2	58.5	57.5	X		X
2	58.4	57.5	X	X	
2	21.6	19.8		X	X
3	58.5	57.0	X	X	X

Table A 32. P-values of PU65 (3-month data)

Term	P-Value
Constant	0.000
TIME	0.000
T	0.977
Q	0.867

Table A 33. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	13.7	0.2	2.0	7.9	13.7	14.6	14.8	15.3
T	90	69.8	0.6	5.6	32.2	70.0	70.8	71.5	78.0
Q	90	17.7	0.3	2.4	14.0	15.2	18.6	20.2	21.1

Regression Eqn of PU65 (3 months data): TA = 11.004 + 0.002450 TIME

- **PU66**

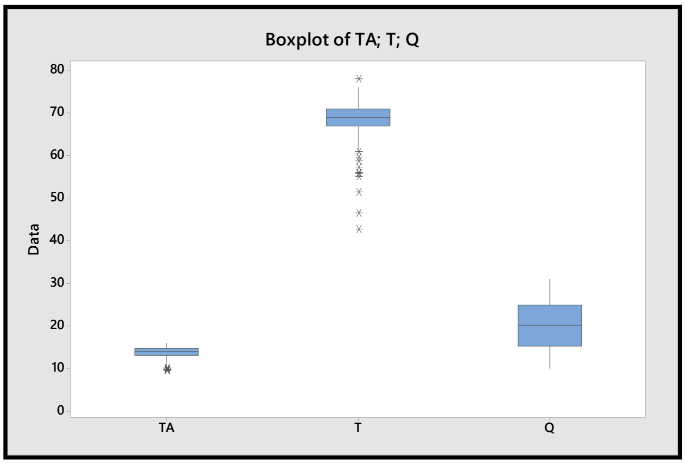

Figure A 7. Box-plot of PU66 data

Table A 34. R-Squared values for PU66 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	4.4	4.1			X		
1	2.6	2.4					X
1	1.2	1.0				X	
1	1.0	0.7		X			
1	0.6	0.4	X				
2	12.5	12.0			X		X
2	9.0	8.6	X		X		
2	7.0	6.5	X				X
2	5.3	4.8			X	X	
2	5.1	4.6		X	X		
3	14.6	14.0	X		X	X	
3	14.6	13.9			X	X	X
3	14.2	13.6		X	X		X
3	13.6	13.0	X	X	X		
3	13.2	12.5	X		X		X
4	20.7	19.9	X	X	X	X	
4	18.5	17.7	X	X		X	X
4	17.8	16.9	X		X	X	X
4	17.0	16.2		X	X	X	X
4	16.9	16.1	X	X	X		X
5	23.3	22.4	X	X	X	X	X

*First 12 months data had very low R-squared value

Table A 35. R-Squared values for PU66 (3 months data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	74.0	73.7	X		
1	21.9	21.0			X
1	8.2	7.1		X	
2	76.3	75.8	X	X	
2	74.1	73.5	X		X
2	23.7	21.9		X	X
3	76.3	75.5	X	X	X

Table A 36. P-values of PU66 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.005
Q	0.984

Table A 37. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	13.1	0.2	1.6	9.5	12.0	13.1	14.9	15.3
T	90	70.8	0.2	1.8	64.0	70.0	71.0	71.9	78.0
Q	90	19.7	0.2	2.0	14.6	19.5	20.3	20.8	25.0

Regression Eqn of PU66 (3-month data): TA = 21.60 + 0.002465 TIME – 0.1577 T

- **PU67**

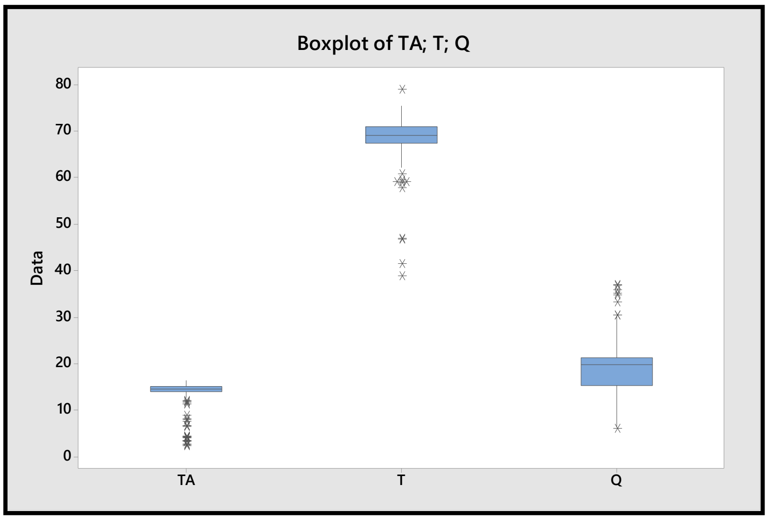

Figure A 8. Box-plot of PU67 data

Table A 38. R-Squared values for PU67 (12-month data)

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	TIME	T	Q
1	16.9	16.6	14.7	82.1	2.1698			X
1	14.3	14.0	12.7	95.9	2.2036	X		
1	0.2	0.0	0.0	169.9	2.3773		X	
2	27.0	26.5	24.4	31.0	2.0369	X		X
2	19.1	18.7	15.8	72.4	2.1435	X	X	
2	17.7	17.2	14.7	80.0	2.1626		X	X
3	32.5	31.9	27.9	4.0	1.9614	X	X	X

Table A 39. P-values of PU67 (12-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.000
Q	0.000

Table A 40. Model summary of PU67 (12-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
1.96136	32.46%	31.89%	27.92%

Table A 41. Descriptive statistics of TA, T and Q (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	360	14.0	0.1	2.4	2.1	14.0	14.5	15.0	16.4
T	360	68.8	0.2	3.8	38.7	67.3	69.1	71.0	79.0
Q	360	19.3	0.3	5.1	5.9	15.2	19.8	21.1	36.9

Regression Eqn of PU67 (12 months data): TA = 4.61 + 0.000404 TIME + 0.1594 T - 0.1741 Q

Table A 42. R-Squared values for PU67 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	59.5	59.1	X		
1	18.4	17.5			X
1	7.0	6.0		X	
2	65.5	64.7	X		X
2	60.3	59.4	X	X	
2	48.3	47.1		X	X
3	66.8	65.6	X	X	X

Table A 43. Model Summary of PU67 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
236.092	66.76%	65.60%	60.18%

Regression Eqn of PU67 (3 months data): TA=-9.4 + 0.003862 TIME + 0.340 T – 0.2947 Q

- **PU68**

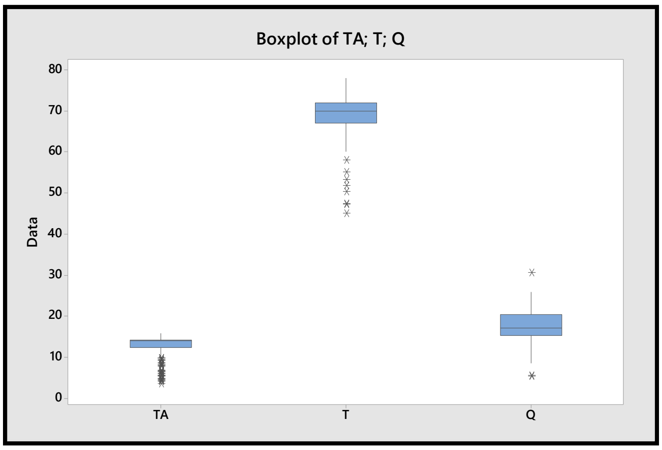

Figure A 9. Box-plot of PU68 data

Table A 44. R-Squared values for PU68 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T^2	Q^2
1	19.7	19.5	X				
1	1.7	1.5				X	
1	1.6	1.3		X			
1	0.7	0.4			X		
1	0.6	0.3					X
2	22.3	21.9	X			X	
2	22.0	21.5	X	X			
2	21.0	20.6	X				X
2	20.6	20.2	X		X		
2	2.4	1.8		X		X	
3	24.0	23.4	X	X		X	
3	23.9	23.3	X			X	X
3	23.6	22.9	X	X			X
3	23.5	22.8	X		X	X	
3	23.1	22.5	X	X	X		
4	25.4	24.5	X	X		X	X
4	25.3	24.4	X		X	X	X
4	24.9	24.1	X	X	X	X	
4	24.9	24.0	X	X	X		X
4	3.1	2.0		X	X	X	X
5	27.1	26.0	X	X	X	X	X

*First 12 months data had very low R-squared value

Table A 45. R-Squared values for PU68 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	55.9	55.4	X		
1	22.4	21.5			X
1	3.4	2.3		X	
2	60.2	59.3	X		X
2	59.2	58.3	X	X	
2	23.0	21.2		X	X
3	64.2	62.9	X	X	X

Table A 46. Model Summary of PU68 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
192.228	64.19%	62.94%	59.66%

Table A 47. P-values of PU68 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.003
Q	0.001

Table A 48. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	10.4	0.3	3.2	3.5	8.0	11.4	13.1	14.5
T	90	71.5	0.2	1.5	66.0	70.8	71.6	72.4	74.7
Q	90	19.5	0.2	2.3	13.0	19.7	20.2	20.7	22.8

Regression Eqn of PU68 (3 months data): TA=34.9 + 0.003837 TIME – 0.491 T + 0.3343 Q

- **PU610**

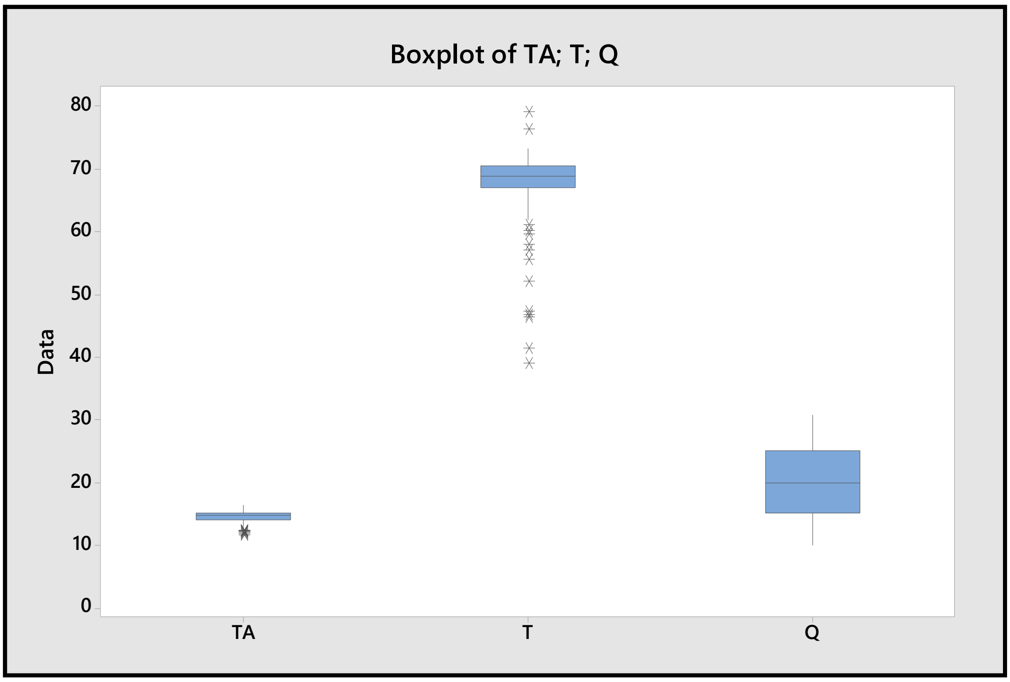

Figure A 10. Box-plot of PU610 data

Table A 49. R-Squared values for PU610 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	38.7	38.5			X
1	36.9	36.7	X		
1	1.1	0.9		X	
2	49.3	49.0	X		X
2	39.7	39.4		X	X
2	38.1	37.8	X	X	
3	49.4	49.0	X	X	X

Table A 50. P-values of PU610 (12-month data)

Source	**P-Value**
Regression	0.000
TIME	0.000
T	0.000
Q	0.099

Table A 51. Descriptive statistics of TA, T and Q (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	360	11.8	0.2	3.9	3.3	11.4	13.8	14.2	16.3
T	360	64.5	0.6	11.6	30.8	66.4	69.0	71.2	77.0
Q	360	18.4	0.2	4.6	6.0	15.1	19.0	21.7	32.5

Regression Eqn of PU610 (12 months data): TA = -2.211 + 0.000794 TIME + 0.1643 T

Table A 52. R-Squared values for PU610 (3-month data)

Vars	**R-Sq**	**R-Sq (adj)**	**TIME**	**T**	**Q**
1	29.3	28.5	X		
1	12.3	11.3			X
1	1.3	0.2		X	
2	36.5	35.0	X		X
2	29.4	27.8	X	X	
2	13.7	11.7		X	X
3	36.6	34.4	X	X	X

Table A 53. P-values of PU610 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.000
T	0.655
Q	0.002

Table A 54. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	14.9	0.05	0.5	13.6	14.7	15.0	15.2	16.0
T	90	71.1	0.3	3.2	46.6	71.0	71.6	72.1	79.0
Q	90	18.4	0.3	2.7	14.0	15.6	19.9	20.3	25.9

Regression Eqn of PU610 (3-month data): TA = 15.422 + 0.000399 TIME – 0.0512 Q

- **PU611**

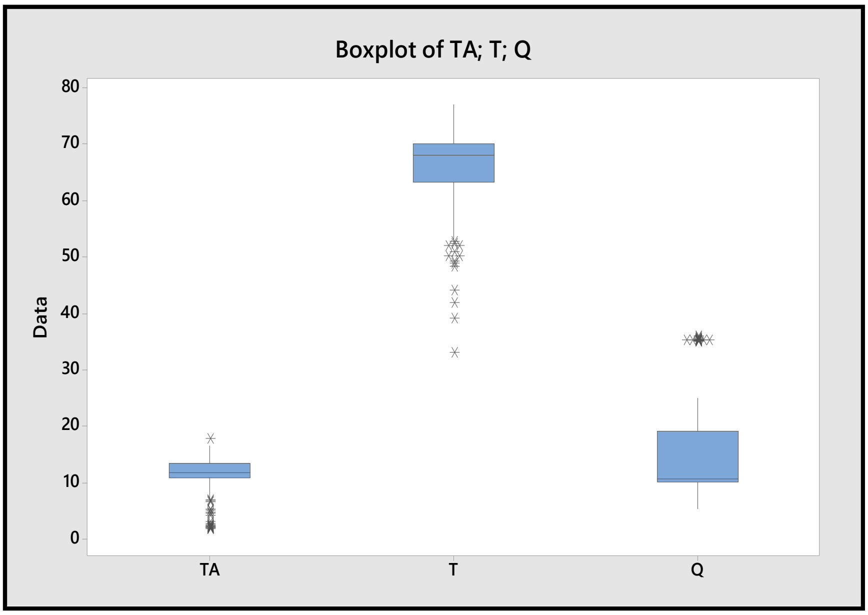

Figure A 11. Box-plot of PU611 data

Table A 55. R-Squared values for PU611 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	43.6	43.4	X		
1	8.9	8.7		X	
2	49.0	48.7	X		X
2	43.6	43.3	X	X	
3	49.2	48.8	X	X	X

Table A 56. P-values of PU611 (12-month data)

Source	P-Value
Regression	0.000
TIME	0.000
Q	0.000
T	0.255

Table A 57. Descriptive statistics of TA, T and Q (12-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	360	11.4	0.1	2.8	1.6	10.8	11.7	13.3	17.8
T	360	65.9	0.3	6.0	32.9	63.2	68.1	70.0	77.0
Q	360	15.3	0.4	7.5	5.3	10.1	10.7	19.0	35.9

Regression Eqn of PU611 (12-month data): TA = 9.136 + 0.000852 TIME – 0.0949 Q

Table A 58. R-Squared values for PU611 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	23.8	22.9	X		
1	11.8	10.8			X
2	25.8	24.1	X		X
2	23.9	22.1	X	X	
3	25.9	23.3	X	X	X

*First 3 months data had very low R-squared value

- **PU612**

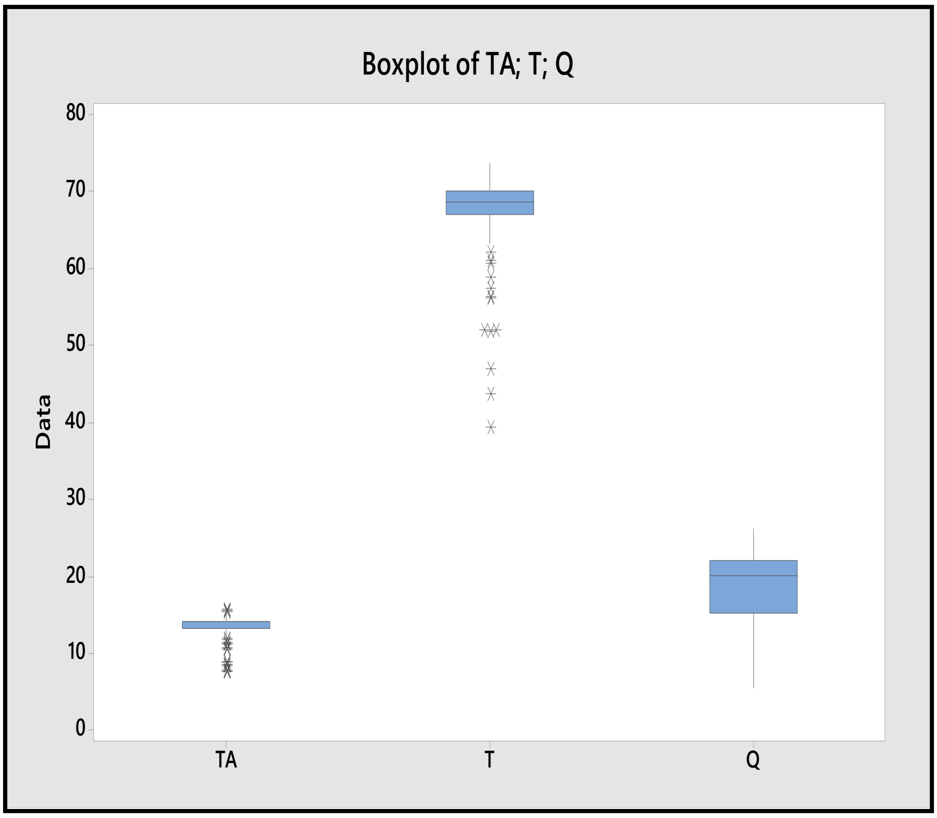

Figure A 12. Box-plot of PU612 data

Table A 59. R-Squared values for PU612 (11-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q	T	Q
1	10.6	10.3	X				
1	8.5	8.2				X	
1	6.8	6.5		X			
1	3.6	3.3			X		
1	3.2	2.8					X
2	28.5	28.0	X				X
2	27.4	27.0	X		X		
2	18.7	18.1		X		X	
2	14.6	14.1	X			X	
2	13.8	13.2	X	X			
3	29.0	28.3	X			X	X
3	28.8	28.1	X	X			X
3	28.6	27.9	X		X		X
3	28.0	27.3	X		X	X	
3	27.8	27.1	X	X	X		
4	31.8	30.9	X	X		X	X
4	30.9	30.0	X	X	X	X	
4	29.2	28.3	X		X	X	X
4	29.0	28.1	X	X	X		X
4	21.9	20.9		X	X	X	X
5	32.0	30.9	X	X	X	X	X

*First 11 months data had very low R-squared value

Table A 60. R-Squared values for PU612 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	68.0	67.7	X		
1	46.1	45.5			X
1	9.7	8.7		X	
2	75.3	74.8	X		X
2	68.9	68.2	X	X	
2	49.9	48.8		X	X
3	76.0	75.2	X	X	X

Table A 61. P-values of PU612 (3-month data)

Source	P-Value
Regression	0.000
TIME	0.000
Q	0.000
T	0.114

Table A 62. Descriptive statistics of TA, T and Q (3-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	90	12.8	0.2	2.2	7.5	11.8	14.0	14.3	15.0
T	90	70.2	0.4	4.1	39.2	69.1	71.0	72.0	73.7
Q	90	16.8	0.3	2.8	10.5	15.1	15.3	19.9	25.0

Regression Eqn of PU612 (3 months data): TA = 14.67 + 0.002311 TIME – 0.2632 Q

- **PL61**

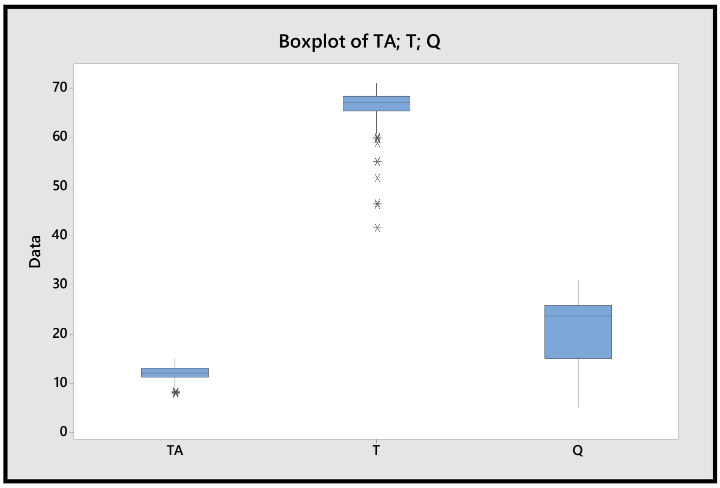

Figure A 13. Box-plot of PL61 data

Table A 63. R-Squared values for PL61 (7-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	39.8	39.5			X
1	37.8	37.5	X		
1	0.4	0.0		X	
2	42.5	41.9	X		X
2	40.4	39.8		X	X
2	38.0	37.4	X	X	
3	43.0	42.2	X	X	X

Table A 64. P-values of PL61 (7-month data)

Source	P-Value
Regression	0.000
TIME	0.003
Q	0.000
T	0.166

Table A 65. Descriptive statistics of TA, T and Q (7-month data)

Variable	N	Mean	SE Mean	St Dev	Min.	Q1	Median	Q3	Max.
TA	200	12.1	0.1	1.7	7.9	11.2	12.0	13.0	15.1
T	200	66.4	0.3	3.9	41.5	65.3	67.0	68.5	71.0
Q	200	21.3	0.5	6.9	5.0	15.1	23.7	25.9	31.0

Regression Eqn of PL61 (7 months data): TA = 9.225 + 0.000353 TIME + 0.0935 Q

Table A 66. R-Squared values for PL61 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	18.9	18.0			X
1	17.6	16.6	X		
1	0.5	0.0		X	
2	23.2	21.4	X		X
2	19.6	17.8		X	X
2	17.7	15.8	X	X	
3	23.5	20.8	X	X	X

*First 3 months data had very low R-squared value

- **PL62**

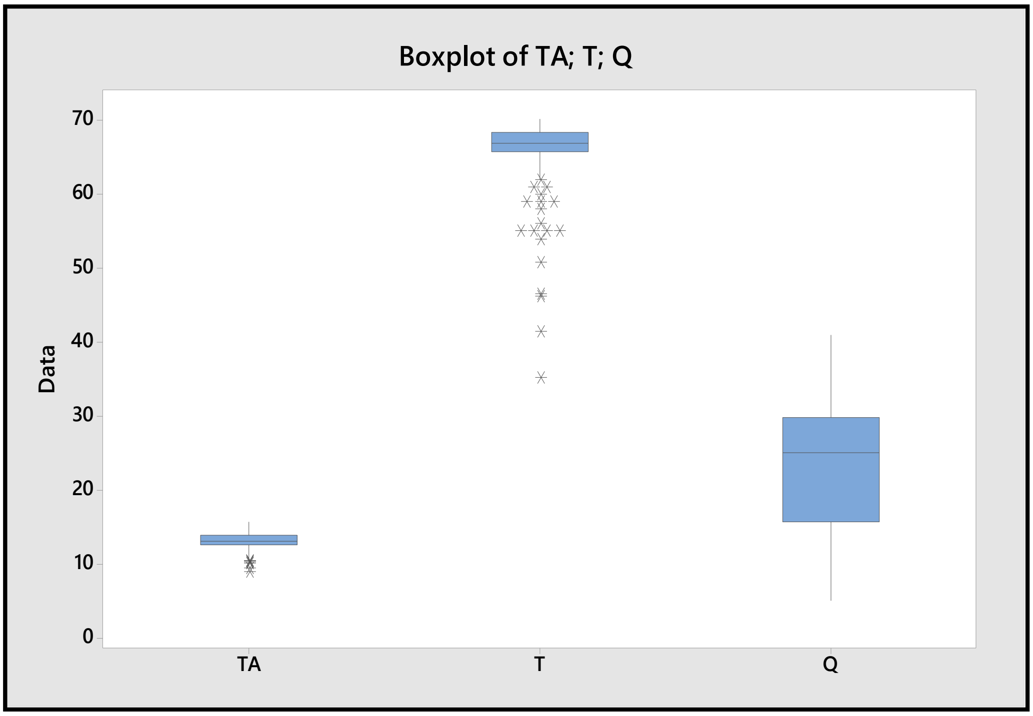

Figure A 14.Box-plot of PL62 data

Table A 67. R-Squared values for PL62 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	13.9	13.6	X		
1	11.8	11.5			X
1	0.0	0.0		X	
2	15.2	14.8	X		X
2	14.1	13.6	X	X	
2	12.1	11.6		X	X
3	15.6	14.9	X	X	X

*First 12 months data had very low R-squared value

Table A 68. R-Squared values for PL62 (3-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	35.0	34.3	X		
1	1.1	0.0		X	
1	0.0	0.0			X
2	36.3	34.8	X	X	
2	35.2	33.7	X		X
2	1.2	0.0		X	X
3	36.7	34.5	X	X	X

Table A 69. Model Summary of PL62 (3-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.820733	36.72%	34.51%	29.90%

Regression Equation of PL62 (3-month data): TA=12.69 + 0.000966 TIME – 0.0250 T + 0.0239 Q

- **PL64**

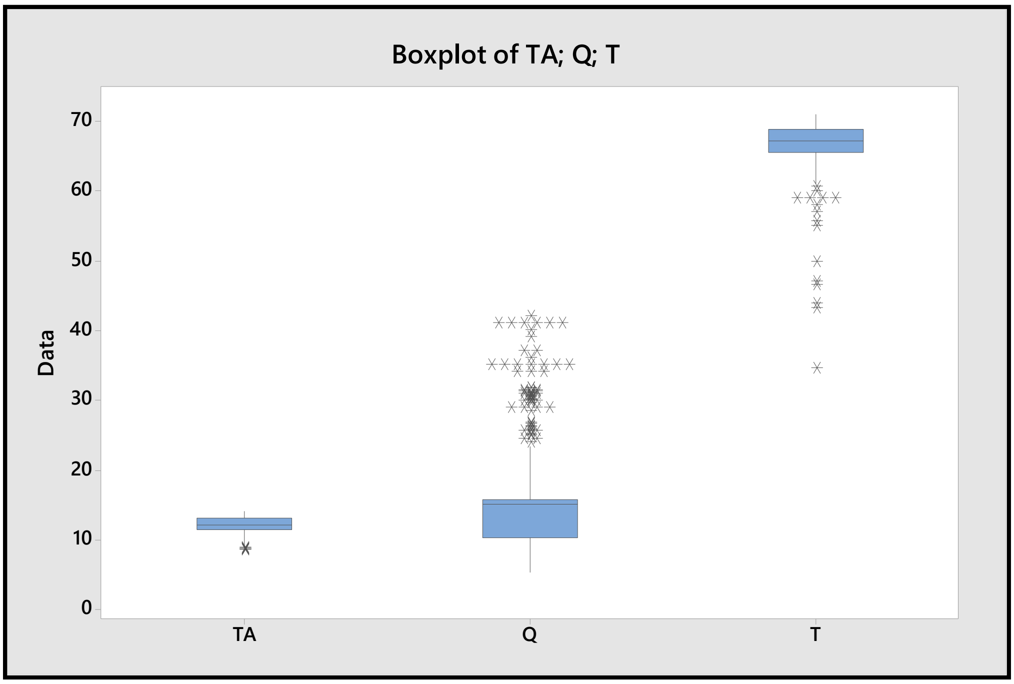

Figure A 15. Box-plot of PL64 data

Table A 70. R-Squared values for PL64 (12-month data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	49.6	49.4	X		
1	27.0	26.8		X	
1	0.2	0.0			X
2	49.8	49.5	X		X
2	49.8	49.5	X	X	
2	27.0	26.6		X	X
3	49.9	49.5	X	X	X

Table A 71. Model Summary of PL64 (12-month data)

S	R-sq	R-sq(adj)	R-sq(pred)
0.867166	49.95%	49.53%	48.40%

Regression Eqn of PL64 (12-month data): TA=9.672 + 0.000326 TIME + 0.00814 Q + 0.0137 T

Table A 72. R-Squared values for PL64 (3 months data)

Vars	R-Sq	R-Sq (adj)	TIME	T	Q
1	9.1	8.0		X	
1	2.6	1.5	X		
1	0.5	0.0			X
2	14.0	12.1	X	X	
2	9.2	7.1		X	X
2	3.6	1.4	X		X
3	14.5	11.5	X	X	X

*First 3 months data had very low R-squared value