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Investigating the quality of Ghori cement based on the composition of raw materials and the way to improve it

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Abstract

In this research, the quality of Ghori cement of Afghani brand has been investigated based on its composition and the analysis and comparison of these compositions with Portland Standard based on ASTM. In this research, the compositions of Ghori cement and Pakistani brand cement have been compared with the Portland ASTM standard.
Since Afghanistan is a developing country and needs to build economic infrastructure, we decided to sample and test the quality of the cement produced in this country in terms of material composition and compare it with Portland cement standard based on ASTM in order to create a quality guarantee for the construction and to compare its quality with foreign competitors (Pakistani cement brands) and it was seen that not only Afghan cement but also Pakistani brands had composition deviations from the Portland Standard based on ASTM.
The results of this research indicate that Ghori cement with a lower amount of silicon dioxide than standard Portland needs to improve its quality, and in this research, we suggested that the loss of quality caused by the lack of silicon dioxide can be improved by using nano silicon.

Keywords: Concrete, Ghori cement, Nano silicon, quality of cement.

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1. Introduction

Cement is the basic component of concrete, which is widely used in construction. The quality of cement directly affects the physical and mechanical properties of concrete. The durability, strength, and security of buildings depend on the quality of cement. Ghori cement factory with Mark 400 with a production capacity of 1400 tpd is the biggest cement factory in the country. Considering the economic importance of this factory in Afghanistan, we decided to determine the quality and position of the cement of this factory by testing the quality of the cement of this factory and comparing it with Portland Standard based on ASTM and finally comparing it with cement brands imported from Pakistan. If the composition of this cement deviates from the Portland standard, upgrade it [1] [2] [3].

According to estimates, more than 300 million tons of cement are consumed in Afghanistan annually, including 778,800 tons of cement produced annually in Ghori Cement, Pol Khomri Cement, Herat Cement, and Samangan Cement factories, which can only supply 0.26% of Afghanistan's needs [4] [5]. Most of the cement required by Afghanistan is imported from neighboring countries. Due to the civil wars and political instability in Afghanistan, these factories have not been destroyed and the work on increasing their production capacity has not been done. This problem has caused Afghanistan to depend on the import of cement from neighboring countries [6].

In this research, an attempt was made to clarify the composition of Ghori cement and the influencing factors of its quality in terms of composition and to resolve it in case of quality reduction. The analysis of Pakistani Ghori and Charat cement was carried out by SPECTRO X-LabPro in the laboratory of the Ministry of Mines and Petroleum AIE and the resulting data were compared with the Portland standard and the only deviation of Ghori cement was in SO3, but the deviation of Pakistani Charat cement was in CaO, SO_3, Na_2O and K_2O_2 was from Portland Standard based on ASTM.

2. Abbreviations

C_3S	Tricalcium silicate ($3CaO.SiO_2$)
C_2S	Dicalcium silicate ($2CaO.SiO_2$)
C_3A	Tricalcium aluminate ($3CaO.Al_2O_3$)
C_4AF	Tetracalcium aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$)
C-S-H	calcium silicate hydrate ($3CaO-2SiO_2-3H_2O$)
AIE	Afghanistan Islamic Emirate

3. Chemistry of Portland cement

Cement is a widely used material in construction and includes di and tri calcium silicate (C_2S, C_3S), tetracalcium Alimofirate (C_4AF), calcium sulfite (gypsum) ($CaSO_4$) compounds. The process of turning cement into a hard form is the process of hydration of the mentioned compounds [2] [7] [8].

3.1. Main Components

According to the Portland cement standard, the composition of clay and limestone should be in intervals as stated in Table 1.

Table 1. Chemical shorthand of cement compounds.

Compound	Formula	Shorthand form	W%
Calcium oxide (lime)	CaO	C	60 to 67%
Silicon dioxide (silica)	SiO_2	S	17 to 25%
Aluminum oxide	Al_2O_3	A	3 to 8%
Iron oxide	Fe_2O_3	F	0.5 to 6%
Sulfate	SO_3	S	1% to 3%
Soda and/or Potash	$Na_2O + K_2O$	N+K	0.5 to 1.3%

After the firing process, the slurry prepared from limestone and clay will change to clinkers in spinner furnace, which has the ingredients listed in Table 2. After grinding, these components are mixed with 7% calcium sulphite (gypsum) and are called cement. By adding water to the cement, which has the components listed in Table 2, these components are hydrated, and a hard material is obtained. This hard material is used as a basic material in building construction. The cement compounds are listed in Table 2.

Table 2. Chemical composition of clinker according to Portland standard.

Compound	Formula	Shorthand form	% by weight
Tricalcium aluminate	$Ca_3Al_2O_6$	C_3A	10
Tetra calcium aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	C_4AF	8
Belite or dicalcium silicate	Ca_2SiO_5	C_2S	20
Alite or tricalcium silicate	Ca_3SiO_4	C_3S	55
Sodium oxide	Na_2O	N	(Up to 2)
Potassium oxide	K_2O	K	
Gypsum	$CaSO_4.2H_2O$	CSH_2	5

Each compound of cement has a specific performance in the hydration process which is shown in Table 3.

Table 3. Effects of the cement compound

Compound	Affect in concrete
Tricalcium aluminate, C_3A	It liberates a lot of heat during the early stages of hydration but has little strength contribution. Gypsum slows down the hydration rate of C_3A. Cement low in C_3A is sulfate resistant.
Tricalcium silicate, C_3S	This compound hydrates and hardens rapidly. It is largely responsible for Portland Cement's initial set and early strength gain.
Dicalcium silicate, C_2S	C_2S hydrates and hardens slowly. It is largely responsible for strength gain after one week.
Ferrite, C_4AF	This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln (from 3,000 °F to 2,600 °F). It hydrates rapidly but does not contribute much to the strength of the cement paste.

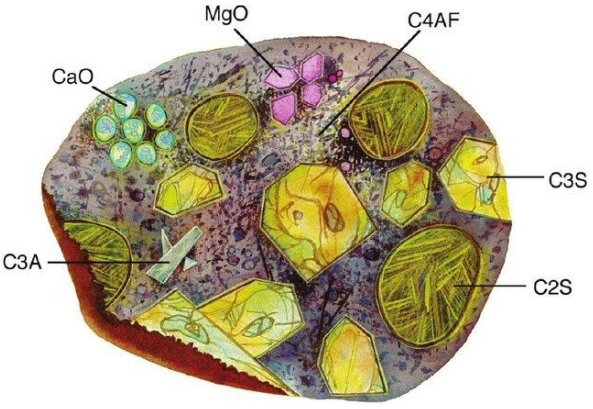


Fig. 1. Microscopic image of the cross-section of a cement grain [9].

3.2. Hydration Process

When cement, as its ingredients are mentioned in Table 3, is mixed with water, it produces compounds such as calcium silicate hydrate or gel (C-S-H), calcium hydrate (C-H), and ettringite. [2] [7].

Calcium silicate hydrate(C-S-H) is obtained from the interaction of C_3S and C_2S with water. Since the composition does not have a fixed stoichiometry, it is only represented as C-S-H. Calcium silicate hydrate(C-S-H) is often obtained from the interaction of C_2S with water, but it can also be obtained from the interaction of C_3S with water with different stoichiometric coefficients.

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH$$

Or (alite) C-S-H gel

$$2Ca_3SiO_4 + 6H_2O \rightarrow 3CaO - 2SiO_2 - 3H_2O + 3(CaO - H_2O)$$

$$2C_2S + 4H \rightarrow C_3S_2H_3 + CH$$

Or (blite) C-S-H gel

$$2Ca_2SiO_5 + 4H_2O \rightarrow 3CaO - 2SiO_2 - 3H_2O + CaO - H_2O$$

3.3. Setting and Hardening

The time required for Portland cement is at least one hour and up to 6.5 hours. The increase and decrease of cement setting are regulated by the amount of gypsum in the cement composition. [2] [7] [10].

The process of cement hydration will continue in time and will continue at a slow rate for more than 100 years [11].

3.4. Modifications

Various additives such as metal oxides (bismuth oxide, zirconium oxide), nanoparticles (graphene oxide, carbon nanotubes, silicon nanoparticles), and calcium agents (calcium chloride) are used to modify Portland cement in the industry. In this research, it is suggested to use nano silicon to improve the hydration process and increase C-S-H production interactions. Because the amount of silicon dioxide, which plays an essential role in the interaction of C-S-H, in the composition of Ghori cement is less than the limit determined by the Portland cement standard based on ASTM, therefore, to compensate for this deficiency, it is suggested to add 2-3% silicon nanoparticles in the raw materials be added. [2] [7] [12].

4. Factors affecting the quality of cement

In this research, an attempt has been made to evaluate the quality of Ghori cement based on the composition of its raw materials. The primary ingredients of cement include limestone and clay, which include aluminum oxide (Al_2O_3) and silicon oxide (SiO_2), and gypsum ($CaSO_4$), each of which plays a vital role in the quality of cement [7] [13]. Limestone is known as the main source of calcium and clay as the source of silicon and aluminum in cement production, and the correct ratio of these two materials, which is arranged by Portland Standard based on ASTM, has a significant impact on the final quality of cement. [7] [13]. The correct ratio of these two compounds (CaO and SiO_2) affects the strength of cement. Gypsum helps in adjusting the setting time of cement. Water quality also affects the hydration process [7] [13]. Considering that the quality of cement is affected by factors such as water quality, quality control in the production stages, environmental conditions, types of additives, and the duration of cement storage, but in this research, the effect of raw material combinations on the quality of Ghori cement has been focused. The information obtained from the analysis of Ghori cement and its comparison with the Portland standard based on ASTM can help in determining its quality from the point of view of the composition of raw materials.

The specifications of standard Portland cement based on ASTM, which is given in Table 4, are very important to ensure the quality and performance of the final product in construction applications so that the amount of cement compounds does not exceed these limits. Calcium oxide (CaO), which is the main component of cement, is between 60-67% of cement and is the main role and raw material in the formation of calcium silicate. The amount of silicon di Oxide (SiO_2), which is 17-25% of the weight of the raw materials in the Portland standard, is necessary to create silicates that maintain high hydraulic properties. The amount of aluminum oxide (Al_2O_3), which helps in the production of calcium aluminate (C_3A) and setting time and strength, should be kept at around 3-8%. Iron oxide (Fe_2O_3) is important for color and citrus formation, which affects cement strength. The presence of magnesium oxide (MgO) should be limited between 0.1-4% because its presence, although it has an effect on the efficiency of cement, its large amount can cause expansion and cracking of cement. The presence of SO_3 controls the setting of cement. Finally, Na_2O and K_2O_2 should be kept between 0.5-

1.3% because these alkaline substances can affect the performance of cement and cause scaling [14].

Table 4. Portland cement composition according to ASTM [14] [8].

Composition	**W%**
Lime (CaO)	60 to 67%
Silica (SiO_2)	17 to 25%
Alumina (Al_2O_3)	3 to 8%
Iron oxide (Fe_2O_3)	0.5 to 6%
Magnesia (MgO)	0.1 to 4%
Sulphur trioxide (SO_3)	1 to 3%
Soda and/or Potash ($Na_2O + K_2O$)	0.5 to 1.3%

5. Comparison of Ghori cement with Portland Standard

Based on the analysis results of Ghori cement and Pakistani Charat cement in SPECTRO X-LabPro device and as the results of this analysis are arranged in table 5 of its compositions and comparing it with Portland Standard based on ASTM, it can be seen that Ghori cement in all compounds except silicon dioxide in Standard range is located in Portland. Ghori cement with 16.63% silicon dioxide (SiO_2) of the Portland standard, which is around 17-25, is 0.35% less than the Portland standards. Charat cement has 59.60% calcium oxide, which is between 60-67% of the Portland range for this composition, has a deviation of 0.40% from the Portland range, and the amount of silicon dioxide in this cement is 16.85%, which is the set limit for this composition. In the Portland standard, it is between 17-25% and the deviation of this composition in Charat cement is 0.15%.

In total, the components of Ghori cement show its strength characteristics and its compatibility with Portland cement, only a small deviation in the amount of silicon dioxide from the standard Portland in its compositions can be observed. Also, according to the components of Charat cement, it can be acknowledged that its composition matches and the deviation of its composition from the Portland standard can be seen in the two compounds of calcium oxide and silicon dioxide, and it is said that this cement is also in close accordance with the Portland standard.

Table 5. Comparison of Ghori and Charat cement with Portland standard.

Components	**Portland**	**Ghori**	**Charat**
Lime (CaO)	60 to 67%	62.62%	59.60%
Silica (SiO_2)	17 to 25%	16.63%	16.85%
Alumina (Al_2O_3)	3 to 8%	4.27%	3.358%
Iron oxide (Fe_2O_3)	0.5 to 6%	2.10%	3.028%
Magnesia (MgO)	0.1 to 4%	1.21%	1.224%
Sulphur trioxide (SO_3)	1 to 3%	1.81%	4.089%
Soda and/or Potash ($Na_2O + K_2O$)	0.5 to 1.3%	0.932+0.2985%	1.273+1.112%

Fig. 2 shows the composition of Ghori and Charat cement in comparison to Portland Standard. The X-axis represents the cement compounds and the Y-axis represents the mass percentage of the compounds. This graph clearly shows the deviation of the silicon dioxide composition of Ghori cement and the deviation of silicon dioxide and calcium oxide of Charat cement from the Portland standard.

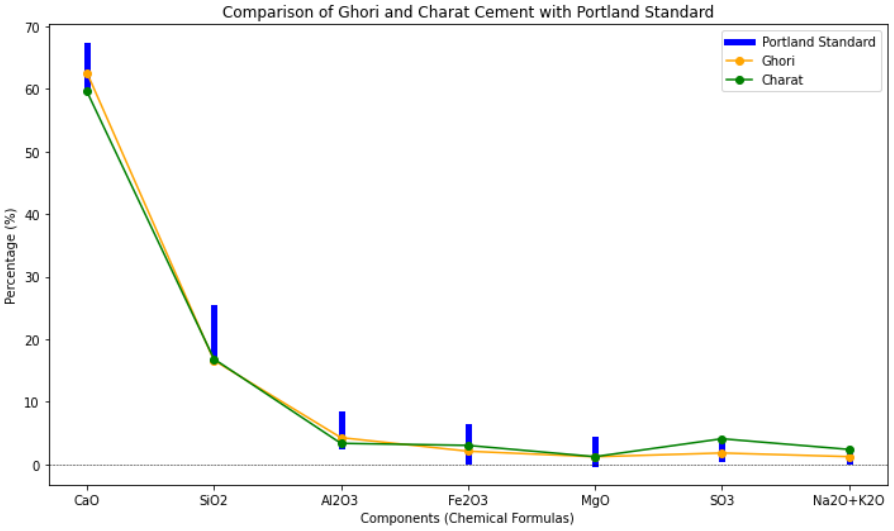


Fig. 2. Component comparison of Ghori and Charat cement with Portland standard.

6. Composition Analysis of Ghori Cement Compared to Portland Cement

Receiving the data from the analysis of Ghori cement and Pakistani Charat, it is analyzed as follows:

Ghori cement, having 16.63% silicon dioxide (SiO_2), shows a decrease of 0.34% compared to standard Portland, which should be in the range of 17-27%, and this deficiency reduces the ability of this cement to produce C-S-H. The maximum amount of production of calcium silicate hydrate (C-S-H) will be possible when the ratio of calcium oxide (CaO) to silicon dioxide (SiO_2) is within the specified range of Portland, otherwise the reduction of silicon dioxide will lead to a decrease in the ability of cement to produce C-S-H.

Charat cement with 59.60% calcium oxide (CaO) and 16.85% silicon dioxide shows at least 0.4% deficiency of calcium oxide and 0.15% silicon dioxide from the Portland standard. The lack of these two basic compounds has led to a decrease in the production level of C-S-H, which is considered the basic component of cement and guarantees the strength and durability of cement.

7. Using nano silicon to improve the quality of Ghori cement

Different additives are used in cement to increase the quality. In this research, by analyzing the quality of Ghori cement, we found that there is a slight decrease in the amount of silicon dioxide in this cement, and we can compensate for this defect by adding nanosilicon [15] [16] [17] [18]. The use of nano-silicon in Ghori cement can increase the percentage of silicon dioxide up to the limits set by the Portland standard, and ultimately improve its quality, which is discussed below in the effects of nano-silicon on cement quality:

7.1. Microstructural Enhancement

Because nano-silicones have very small dimensions by filling the empty spaces between the cement, can cause a denser structure and improve the density of the cement. Reducing porosity in cement makes cement durable and strong. [17] [16].

7.2. Pozzolanic Activity

The compressive, tensile, and bending strength of cement depends on the amount of C-S-H gel in the cement, and the amount of C-S-H gel production depends on the exact proportions of calcium oxide and silicon dioxide. Therefore, a decrease in the amount of silicon dioxide can cause a decrease in the mechanical properties of cement. In this research, it is recommended to use nano silicon to compensate for the lack of silicon dioxide, which will produce C-S-H gel at the desired level [17] [16].

7.3. Accelerating the hydration process

Nano-silicon helps the hydration process of cement and makes the setting time of cement faster and gypsum, on the contrary, makes the setting time of cement slower. In some cases, if there is a need to speed up the construction process, this material can increase its speed and set its time as desired [17] [16] [19].

7.4. Improving the durability of cement

The addition of nano-silicon increases the physical and mechanical properties of cement and ultimately makes it durable. Nano silicon reduces the porosity, which reduces the permeability of cement and prevents the entry of harmful substances such as chlorides and sulfates into the cement. Increasing mechanical resistance and reducing impermeability make cement durable [17] [20].

7.5. Optimal Dosage

Research shows that the optimal dosage of nano silicon is between 2-3% in terms of strength and durability. This amount must be controlled in cement because increasing the amount of nano-silicon can cause negative performance in cement [16].

Considering the multifaceted properties of nano silicon to improve the quality of cement, including microstructural properties, acceleration of hydration, durability, and pozzolanic activity, we came to the conclusion that this additive can be used both as an increaser of silicon dioxide and as an enhancer of cement quality.

8. Comparison of Ghori cement with Pakistani brands in terms of ingredients

Ghori cement with a balanced composition and brand 400 is one of the largest production factories in Afghanistan with a production capacity of 1400 tons per day. In this research, an effort was made to evaluate the quality of this cement from the point of view of the composition of raw materials. In terms of the composition of raw materials, this cement is 0.37% less than the Portland Standard in terms of the amount of silicon dioxide listed in Table 6 of its ingredients, and it is in accordance with the Portland Standard in all its ingredients. In contrast to Charat cement, it has been analyzed in this research that Charat cement is lower than Portland Standard in the two compounds of calcium oxide and silicon dioxide. The remaining compounds of other Pakistani cements have been identified and compared from research.

Table 6. Comparative analysis of the chemical compositions of Ghori cement and various Pakistani brands [24].

Components	**Portland**	**Ghori**	**Charat**	**lucky**	**askari**	**bestway**	**mustehkam**
Lime (CaO)	60 to 67%	62.62%	59.60%	62.89	62.6	61.7	61.24
Silica (SiO_2)	17 to 25%	16.63%	16.85%	20.78	20.12	21	20.75
Alumina (Al_2O_3)	3 to 8%	4.27%	3.36%	5.11	5.53	5.04	5.3
Iron oxide (Fe_2O_3)	0.5 to 6%	2.10%	3.03%	3.17	3.47	3.24	4.26
Magnesia (MgO)	0.1 to 4%	1.21%	1.22%	3	1.71	2.56	2.03
Sulphur trioxide (SO_3)	1 to 3%	1.81%	4.09%	1.74	2.29	1.51	1.82
Soda and/or Potash ($Na_2O + K_2O$)	0.5 to 1.3%	0.932+0.2985%	1.273+1.112%	2.31	1.45	1.83	1.53

In the figure. 3, the comparison of Ghori cement compositions with Pakistani cement brands (Charat, Lucky, Askari, Bestway, and Mustehkam) and Portland Standard is evaluated and it can be seen in which combination each brand is out of Portland Standard.

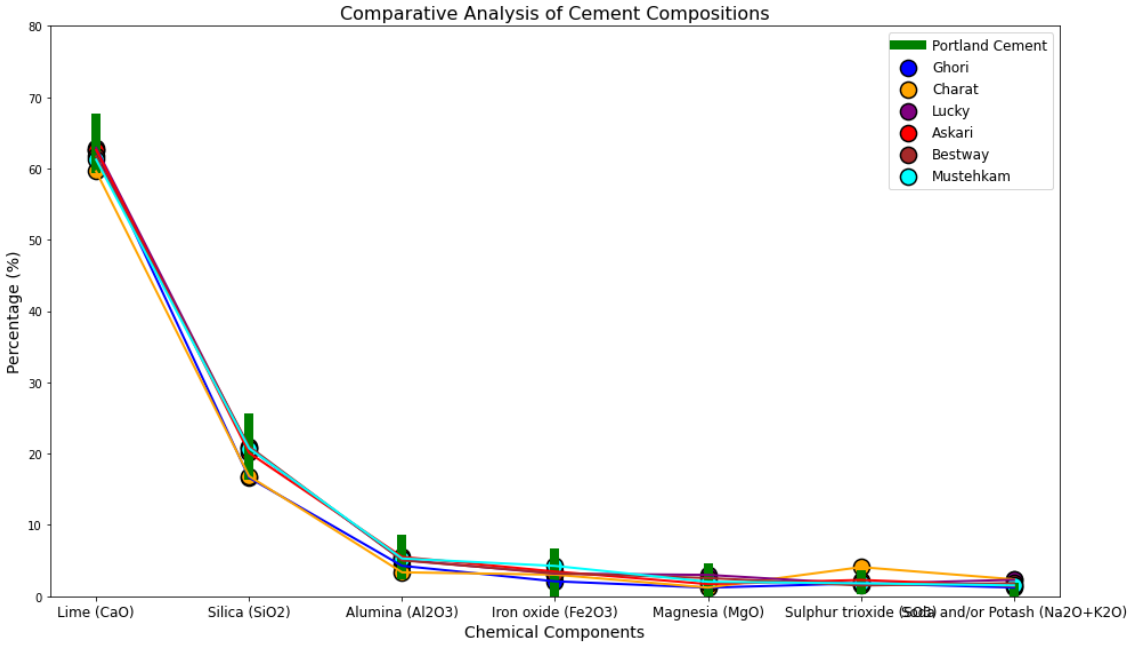


Fig. 3. Comparative analysis of Ghori cement and Pakistani brands.

9. Conclusion

This research shows the quality of Ghori cement based on the composition of raw materials. The findings of this research indicate that the quality of this cement is commendable in terms of raw materials and shows a small deviation in the amount of silicon dioxide. In this research, it is suggested to avoid this defect, silicon nanoparticles can be used to improve its quality.

Charat cement has also been analyzed in this research and it has praiseworthy quality in terms of the composition of raw materials. According to the Portland standard, this cement deviates from the Portland standard in two combinations: the amount of silicon dioxide and the amount of calcium oxide.

The cement production industry in Afghanistan has a great market because the annual demand for this product shows the significant demand for this product in the market so all the cement factories of this country can only supply 0.26% of the cement requirement of this country.

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Authors Profile



Ainullah Yasini, son of Mohammad Yasin, completed his primary education from 1382 to 1393 at Baharistan High School in Baharak District, Badakhshan province, and then continued his higher education in the field of Chemical Technology Engineering at Balkh University, which started in 2015 and ended in 2019. He joined the academic staff of Kabul Polytechnic University in 2024 and is currently an instructor in the Department of Chemical Engineering, Faculty of Chemical Engineering, Kabul Polytechnic University.



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Asraruddin Gulzad, son of Bashiuddin Akhundzada, was born in 1959 in Galai village of Ghani Khel district of Nangarhar province in a religious family. He joined Ghani Khel Primary School in 1956 and Email Khan High School in 1973. In 1977, he entered the Faculty of Natural Sciences of Kabul University and was sent abroad to study engineering. In 1982, he graduated from the Azerbaijan Academy of Oil, Gas, and Chemistry with a master's degree. In 2015, he was sent abroad to obtain a doctorate degree. In May 2018, he successfully defended his doctoral thesis. He also served as the head of this department from 1996 to 2004 and from 2013 to 2016 as the head of student affairs and head of the preparatory faculty of Kabul. Among the scientific activities of Prof. Dr. Asraruddin Gulzad, eight textbooks, and 69 scientific-research articles have been published in domestic and international journals. He taught organic chemistry and performed meritorious services and is currently working as the head of the Petroleum and gas chemical industry engineering department.