Afro-Asian Journal of Scientific Research (AAJSR)
المجلة الأفروآسيوية للبحث العلمي
E-ISSN: 2959-6505
Volume 4, Issue 3, 2026
Page No: 112-125
Website: https://aajsr.com/index.php/aajsr/index
SJIFactor 2024: 5.028 ISI 2025: 0.915 معامل التأثير العربي (AIF) 2025: 0.76

Design and Economic Evaluation of a Natural Gas Transmission Pipeline as an Alternative Fuel Supply for Souk Al-Khamis Cement Plant, Libya

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تصميم وتقييم اقتصادي لخط نقل الغاز الطبيعي لتوفير وقود بديل لمصنع سوق الخميس للأسمنت، ليبيا

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Received: May 10, 2026	Accepted: July 18, 2026	Published: August 04, 2026

Abstract:
Natural gas serves as a critical driver for modern heavy industries due to its high thermal efficiency and environmental sustainability. In Libya, the cement industry represents the backbone of infrastructure development; however, relying on conventional liquid fuels such as heavy fuel oil poses significant economic and environmental challenges. The primary objective of this study was to design a natural gas transmission pipeline to serve as a stable, safe, and continuous gas fuel supply for the Souk Al-Khamis cement plant in Libya. The study methodology followed standard pipeline design formulas from ASME B31.8 and API 5L codes and specifications. Route selection was conducted using Google Earth application. Secondary data of the gas, including flow rate, pressure, and temperature, were collected, and an empirical study was conducted to predict the nature of the gas and to calculate its physical properties .Hydraulic design formulas based on the Weymouth equation and Barlow's formula were used to calculate pipe diameter, inlet and outlet gas velocities, pipe wall thickness, pipe schedule number, maximum operating pressure, burst pressure, hydro test pressure, and gas pressure drop. The resulting values were: 12 inches, 7.15 ft/s, 14.3 ft/s, 0.19inch, schedule number 14.0, maximum operating pressure 48.8 bar, burst pressure 108.5 bar, hydro test pressure 61 bar, and pressure drop 14 bar. The results demonstrate that the proposed design is technically feasible, economically viable, and significantly contributes to carbon emission reduction.

Keywords: Natural Gas Pipeline, Cement Industry, Hydraulic Design, Weymouth Equation.

الملخص
يُعد الغاز الطبيعي محركًا رئيسيًا للصناعات الثقيلة الحديثة، نظرًا لما يتمتع به من كفاءة حرارية عالية واستدامة بيئية. وفي ليبيا، تمثل صناعة الأسمنت الركيزة الأساسية لتطوير البنية التحتية؛ إلا أن الاعتماد على أنواع الوقود السائل التقليدية، مثل

زيت الوقود الثقيل، يفرض تحديات اقتصادية وبيئية كبيرة. تمثّل الهدف الرئيسي من هذه الدراسة في تصميم خط أنابيب لنقل الغاز الطبيعي بهدف توفير إمداد مستقر وآمن ومستمر من وقود الغاز إلى مصنع سوق الخميس للأسمنت في ليبيا . اتبعت منهجية الدراسة معادلات التصميم القياسية الخاصة بخطوط الأنابيب، وفقًا لمعايير ومواصفات *ASME B31.8* ، *API 5L* وتم اختيار مسار خط الأنابيب باستخدام تطبيق القوقل ايرث كما جُمعت البيانات الثانوية المتعلقة بالغاز، بما في ذلك معدل التدفق والضغط ودرجة الحرارة، وأُجريت دراسة تجريبية للتنبؤ بطبيعة الغاز وحساب خواصه الفيزيائية. استُخدمت معادلات التصميم الهيدروليكي، المستندة إلى معادلة ويمي ومعادلة بارلو، لحساب قطر الأنبوب، وسرعتي الغاز عند المدخل والمخرج، وسُمك جدار الأنبوب، ورقم جدول الأنبوب، وضغط التشغيل الأقصى، وضغط الانفجار، وضغط اختبار الضغط الهيدروستاتيكي، وكذلك هبوط ضغط الغاز على طول خط الأنابيب. أظهرت النتائج أن القيم المحسوبة كانت على النحو الآتي:قطر الأنبوب 12 بوصة، سرعة الغاز عند المدخل 7.15 قدم/ثانية، سرعة الغاز عند المخرج 14.3 قدم/ثانية، سُمك جدار الأنبوب 0.19 بوصة، رقم جدول الأنبوب 14.0، ضغط التشغيل الأقصى 48.8 بار، ضغط الانفجار 108.5 بار، ضغط الاختبار الهيدروستاتيكي 61 بار، وهبوط الضغط 14 بار. أظهرت النتائج أن التصميم المقترح قابل للتنفيذ من الناحية الفنية، ومجدٍ من الناحية الاقتصادية، ويسهم بصورة ملحوظة في خفض انبعاثات الكربون.

الكلمات المفتاحية: انبوب الغاز الطبيعي، صناعة الاسمنت، التصميم الهيدروليكي، معادلة ويمي.

Introduction

The cement industry is an energy-intensive process, utilizing thermal and electrical energy in various production phases, from grinding raw materials to burning clinker (clinker is the material produced by burning raw materials in the rotary kiln.The production of cement consumes large quantities of raw materials and energy (thermal and electricity). This process requires approximately 3.2 to 6.3 GJ of energy and 1.7 tons of raw materials (mainly limestone) per ton of clinker produced. Being an energy intensive industry, thermal energy used in cement industry accounts for about 20–25% of the production cost. The typical electrical energy consumption of a modern cement plant is about 110–120kWh per ton of cement.

In the manufacturing process thermal energy is used mainly during the burning process, while maximum share of electrical energy is used for cement grinding .The cement manufacturing process has a substantial environmental impact, primarily due to its high energy consumption, significant carbon dioxide (CO2) emissions, and the release of various pollutants [1].The cement industry is a major contributor to CO_2 emissions, with total CO_2 emissions from the cement industry worldwide estimated at 1.6 billion metric tons annually, representing approximately 8% of total global emissions [2]. The majority of these emissions arise from the combustion of fossil fuels such as coal and heavy fuel oil (HFO) used to generate the high temperatures required in rotary kilns [2].

The cement industry is classified by the U.S. Environmental Protection Agency (EPA) as the third largest industrial polluter globally, releasing more than 500 kilotons of nitrogen oxide, sulfur dioxide, and carbon monoxide annually [3]. Many countries have adopted strategies to reduce these emissions, represented by improving energy efficiency, transitioning to low-carbon fuels, enhancing the efficiency of materials used in the industry, and developing innovative production methods and raw materials approaching net zero carbon emissions. The latter two significantly contribute to reduce emissions [4]. The use of alternative fuel (AF) has becomes increasingly popular cement manufacturer due to increasing fossil fuel prices, limited fossil fuel resources and environmental concerns [5].

Studies have been conducted confirming that the steel reheating furnaces fueled by heavy oil are significant air pollutants and using natural gas in these furnaces reduces the amount of pollutants and oxides emitted. The combustion products of natural gas contain half the amount of carbon dioxide compared to coal, and about two-thirds of the amount compared to heavy fuel oil. Natural gas, when used as a fuel, has been shown to reduce emissions by 50%.Therefore, it is possible to develop and enhance the efficiency of fuels and furnaces to minimize heat losses, as furnaces operating with natural gas fuel demonstrate higher efficiency compared to those using heavy fuel oil [5].

In many African and Middle Eastern countries, including Libya, cement plants rely heavily on heavy fuel oil due to limited infrastructure for cleaner fuels. However, natural gas has emerged as a cleaner and more efficient alternative due to its high calorific value, lower carbon intensity, and ease of combustion [4]. The transition from heavy fuel oil to natural gas requires the development of reliable gas supply systems, including the design of transmission pipelines that ensure safe, continuous, and efficient delivery of gas to industrial facilities [6]. The Souq Al-Khamis Cement Factory is one of the most strategic industrial facilities in western Libya. It is a key subsidiary of the National Cement Company (ASCC). The factory is situated in the Souq Al-Khamis Msihel area, approximately 60 kilometers south of the capital, Tripoli. The Souq Al-Khamis complex consists of multiple production lines. While the design capacity is high, actual output can fluctuate based on maintenance cycles and power stability. The factory utilizes the dry Process technology, which is more energy-efficient, compared to older wet

process kilns. Energy is the most significant cost factor for the Souq Al-Khamis factory. Currently this factory uses heavy fuel oil (HFO) as a fuel [7].
One of the main challenges faced by the factory related to the type of fuel used currently, these challenges are represented in fuel cost, maintenance costs associated with liquid fuel systems, fuel storage and handling complexity, lower combustion efficiency, increased greenhouse gas emissions. All these challenges may limit the factory's ability to operate at full capacity and necessitate the development of an alternative fuel supply system based on natural gas [8]. The absence of an optimized gas pipeline infrastructure for industrial use limits the adoption of natural gas. Therefore, there is a need to design an efficient and cost-effective natural gas pipeline system to replace conventional fuel sources in cement plants. This study is conducted to design a safe and hydraulically efficient natural gas pipeline sever as fuel source to the Souk Al-Khamis cement plant.
This study focused on studying the design of a natural gas pipeline to serve as alternative fuel source for Souk Al-Khamis cement plant in order to overcome the challenges faced by the factory while using heavy fuel oil as a fuel. The design study involves estimating the physical properties of the natural gas, performing hydraulic calculations to determine the optimum pipeline diameter, selecting materials of designed pipeline compliant with international safety standards, estimating the design pressure of the designed pipeline and evaluation the economic feasibility of substituting heavy fuel oil with natural gas as fuel.

Methodology:

Data Collection

The data employed in this study were sourced from the General Company for Gas Transmitting and Distribution (GGTDC), these data were utilized to assess gas properties and to compute the additional parameters required for the gas pipeline design procedure [9]. The obtained data are listed as below**:**

Gas Composition

The used composition of the natural gas is shown in Table1.0 below:

Table 1: Field Gas Composition [9].

Number	Compound	Mole Fraction (Y_i)	Molecular weight (M_i) g/mol
1	Carbon dioxide	0.024	44
2	Nitrogen	0.058	28
3	methane	0.8368	16
4	Ethane	0.0883	30
5	propane	0.0271	44
6	I-Butane	0.0054	58
7	N-Butane	0.0066	58
8	I-Pentane	0.0026	72
9	N-Pentane	0.0019	72
10	Hexane +	0.0015	86

Gas Pressure -Temperature - Heating Value and Flow Rate

The gas data which are pressure, temperature and gas capacity needed by Souk Al-Khamis Cement Plant as gained from (GGTDC), also the distance between the national Libyan gas network connection point to the Souk Al-Khamis cement plant are as the following:

- Inlet pressure = (20-36) bar.
- Minimum Outlet delivery Pressure = 14 bar.
- Inlet flowing temperature (Tf) = 70 F0.
- Gas capacity (Qg) = 14MMSCF/D (16518.16m3/hr).
- Base pressure and temperature (Pb = 14.7 psi, Tb = 60 F0).
- Natural Gas Heating Value (HVGas) = 36 MJ /m3

There is no effect for elevation on pipe pressure and the pipeline will be designed as horizontal pipe [9].

Data from Souk Al-Khamis Cement Plant

- Plant production capacity = 1000000 ton /year
- Plant Annual heavy fuel oil consumption = 130229 ton / year
- Heating Value of heavy fuel oil = 40 MJ /Kg [8,9,10].

Rote Selection for Proposed Pipeline

Based on a field study conducted by the General Company for Natural Gas Transmission and Distribution (GGTDC) to determine the safest and shortest route for designing a natural gas pipeline to supply the Souq Al-Khamis Cement Factory as fuel via a connection point through the (Al-Khamis - Al

Aziza gas pipeline), and with the help of Google Maps, it was found that the length of the pipeline route was 24 kilometers. The location coordinates of the proposed line is shown in figure 1.0 below [9].

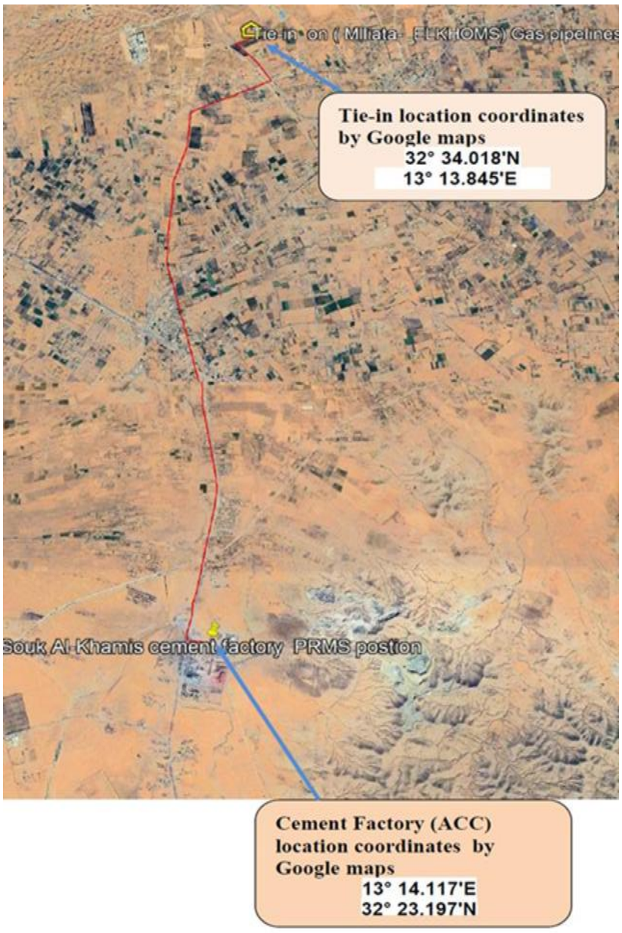

Figure 1: Proposed Gas Pipeline route for Souk Al-Khamis Cement Factory [9].

Estimation of Natural Gas Properties

Determination of Gas Apparent Molecular Weight (Ma)

The gas molecular weight (M_a) is estimated using the following formula [11]:

$$M_a = (\sum_{i=1}^{n} Yi \times Mi) \qquad (1)$$

Where**:** Yi: the mole fraction of component *i* in gas mixture, Ma: the molecular weight of component *i .*

Determination of Gas Gravity (G)

The gas gravity (G) is estimated from the following formula [12]**:**

$$G = \frac{M_a}{M_{air}} \qquad (2)$$

Where: M_{air} is the molecular weight of the air which equal to 28.96 g/mol.

Determination of Gas Compressibility Factor (Z)

The gas compressibility factor is evaluated using Katz and standing chart based on the psedo-reduced temperature and pressure as the following**:**

A. Estimation of the pseudo-critical temperature (T_C) and pressure (P_C) using the following correlation**:**

$$P_C = 677 + 15G - 37.5G^2 \qquad (3)$$

Where G: is the gas Gravity, P_C critical temperature (psia).

$$T_C = 168 + 325G - 12.5G^2 \qquad (4)$$

Where T_C**:** is the critical temperature (R^0).

B. Calculation of the pseudo-reduced temperature (Tr) and pressure (Pr)

$$T_r = \frac{T}{T_C} \qquad (5\text{-a})$$

$$P_r = \frac{P_{avg}}{P_C} \qquad (5\text{-b})$$

Where**:** T is the flowing inlet temperature of the gas (R^0).

P_{avg}**:** is the average pressure of the gas which is estimated from the following equation**:**

$$P_{avg} = \frac{2}{3}\left(\frac{P_1^3 - P_2^3}{P_1^2 - P_2^2}\right) \qquad (6)$$

Where**:** P_1, P_2 are the inlet and outlet pressures of the gas through the pipe (psi) [13, 14].

Determination of Gas Density (ρ)

The gas density is calculated by the following Formula [13]**:**

$$\rho = \frac{P_{avg} M_a}{ZRT} \qquad (7)$$

Where**:**

ρ**:** The gas density (b/ft^3), Pavg**:** The average pressure of the gas (psi).

Ma**:** Apparent molecular weight of the gas(b/mol), Z**:** Gas deviation factor.

T**:** Inlet flowing temperature of gas (R^0), R**:** The gas constant which equal to (10.73 ft^{3}psi / mol. R^0)

Determination of Gas Viscosity (μ)

The viscosity of natural gas mixture is determined by the correlation developed by Lee, et .al in (1966) as shown in equation (8) below**:**

$$\mu_g = K.\,10^{-4} e\left(X \rho_g^Y\right) \qquad (8)$$

Where:

$$K = \frac{(9.4 + 0.02M)T^{1.5}}{209 + 19M + T}\ , \quad X = 3.5 + \frac{986}{T} + 0.01\,M\ , \quad Y = 2.4 - 0.2\,X$$

μg: dynamic viscosity of gas mixture (cp), M: molecular weight of gas mixture.

T: gas Temperature (R^0), ρ_g: gas density (g /cm^3) [14].

Pipeline Sizing

Determination of Pipe Diameter

The inside pipe diameter (d) is estimated using Weymouth equation as shown in equation (9) below. In addition, a computational method can be applied through using an Application software online (checalc): Natural gas pipeline sizing at**:** (https://checalc.com/solved/gasPipeSizing.html.) which allows for determining the optimal pipeline diameter while taking into account the required quantity of fuel needed by the plant. This approach involves performing multiple steps by selecting a pipe diameter and comparing the calculated value of gas capacity with the required capacity by cement plant.

$$Q_g = 1.42\, d^{2.67} \left[\frac{P_1^2 - P_2^2}{LZGT}\right]^{1/2} \qquad (9)$$

Where:

Qg: The flowing gas flow rate (capacity) (m^3/hr) , d: The inside pipe diameter (mm).

P1 and P2 are the flowing inlet and outlet gas pressures through the pipe (Kpa).

L: The length of the pipe (m), Z: The gas deviation factor, G: The gas gravity.

T inlet gas temperature (K^0) [15].

Based on the collected data for the requested amount of gas by Souq Al Khamis cement factory and duo to the variation gas inlet pressure all the time thought the year due to some technical problems related to gas supplier this issue must be taken into account while estimating the designed pipeline diameter. The first guess of estimating pipe diameter is conducted based on least value of inlet gas pressure available then the resulted value is checked with the other values of gas inlet pressure by using the Application software online (che.calc) Natural gas pipeline sizing at: (https://checalc.com/solved/gasPipeSizing.html.) If obtained diameter value was not enough to deliver the requested value of the gas capacity which needed by cement factory at low values of the inlet gas pressure, so we must select other value of pipe diameter again by using (checalc) Application software online until we make sure that the obtained diameter value will be enough to deliver the requested value of gas capacity needed by the cement factory.

Determination of Gas Velocity in Pipeline

The gas velocity at any point in a pipeline is estimated from the equation (10) as below:

$$u = 0.002122\left(\frac{Q_b}{D^2}\right)\left(\frac{P_b}{T_b}\right)\left(\frac{ZT}{P}\right) \quad (10)$$

Where: u: Gas velocity (ft/s), Qb: Gas flow rate, measured at standard condition (ft3/day)
D: Pipe inside diameter (in), Pb:base pressure (psia) , Tb: base temperature (R0)
P: gas pressure (psia), T: Average gas flowing Temperature (R0)
Z: Gas compressibility factor at flowing temperature [11].
The upper limit of gas velocity in a pipeline is approximately calculated from the following equation:

$$\mathrm{U_{max}} = \frac{100}{\sqrt{\rho}} \quad (11)$$

where:
Umax: maximum or erosional velocity (ft/s ,
ρ: gas density at flowing temperature (Ib/ft3)[11].

Determination of Pipe Nominal Thickness
The nominal wall thickness of pipe is calculated using Barlow equation (12) below:

$$t_{NOM} = \frac{P_d\,D}{2\epsilon_w \eta \delta_y F_t} + C_a \quad (12)$$

Where:
tNom: nominal wall thickness (mm), Pd: Design internal pressure (psi)
D: internal inside diameter of pipe (mm), Єw: weld efficiency factor for pipe
δy:specified minimum Yield strength of pipe , η: design factor
Ft: temperature derating factor, Ca: corrosion allowance thickness (mm) [16].
Determination of Pipe Schedule Number
The schedule number of the pipe is estimated from the following Formula:

$$\mathrm{Sn} = 1000 \times \frac{\mathrm{P}}{\mathrm{S}} \quad (13)$$

Where:
Sn: pipe schedule number, P: design internal pressure (psi)
S: Specified minimum yield strength of pipe (psi) [16].

Determination of Reynolds Number and Friction Factor

The Reynolds number for the gas flow in pipeline is evaluated from the equation14 below [17]**:**

$$N_{Re} = 0.0004778 \left(\frac{Pb}{Tb}\right)\left(\frac{GQ}{\mu D}\right) \quad (14)$$

Where:

N_{Re}: Reynolds number, Q: gas flow rate (SCF/D), μ: gas viscosity (b/ft-s)

D: pipe inside diameter (in), G: gas gravity, Pb:base pressure (psia) , Tb: base temperature (R^0)

The friction factor of the pipe for turbulent flow can be estimated from the equation 15 below [17]:

$$f^{0.5} = \frac{1}{2\log\left(\frac{D}{\varepsilon}\right)+1.14} \quad (15)$$

Where:

f: friction factor of pipe, D: pipe inside diameter (in), ε: Pipe roughness (inch).

Determination of Gas Pipeline Design Pressures

Maximum Allowable Pipeline Operating Pressure (MAOP)

The maximum of allowable pipeline operating pressure is calculated from the following formula:

$$MAOP = 2 \times F \times SMYS \times \frac{t}{D} \quad (16)$$

Where: MAOP: maximum of allowable operating pressure pipeline (psi)

F:design factor for natural gas pipelines, t: pipe wall thickness (mm)

D: pipe inside diameter (mm), SMYS: specified minimum yield strength of pipe material (psi) [18].

Pipeline Bursting Pressure (BP)

The bursting pressure of pipeline is evaluated from the following formula:

$$BP = 2 \times (SUTS) \times \frac{t}{D} \quad (17)$$

Where: BP: the bursting pressure of gas pipeline (psi),

SUTS: the specified ultimate tensile strength of pipe material (psi)

D: pipe inside diameter (mm), t: pipe wall thickness (mm) [13].

Plastic Collapse Pressure (PY)

The plastic collapse pressure of the gas pipeline (psi) is estimated from the following equation [13]:

$$P_Y = 2 \times SMYS \times \frac{t}{D} \quad (18)$$

Hydro Test Pressure (HT)

The maximum hydro test pressure of pipeline (psi) is evaluated from the following formula [12]:

$$H_T = 1.25 \times MAOP \quad (19)$$

Pressure Drop (ΔP)

The pressure drop of the gas through the pipeline (psi) is calculated from the following formula [12]:

$$\Delta P = P_1 - P_2 \quad (20)$$

Where**:** P_1, P_2 are inlet and outlet pressure of the gas through the pipeline.

Economic Comparison between Heavy Fuel Oil and Natural Gas as Consumption

This economic assessment compares the annual fuel cost of the current Heavy Fuel Oil (HFO) system with the proposed Natural Gas (NG) system for a studied cement plant producing 1,000,000 tons of cement per year. The objective of this fuel comparison is to evaluate the potential cost savings resulting from replacing HFO with natural gas while maintaining the same thermal energy input to the cement production process. The calculation steps for economic evaluations are presented in the following paragraphs.

Annual Cost of Heavy Fuel Oil (HFO)

Annual cost of heavy fuel oil is estimated from the following formula [19]:

$$\text{Annual Cost of HFO} = \text{Annual HFO Consumption} \times \text{HFO Price} \qquad (21)$$

Annual Cost of Proposed Natural Gas (NG)

Annual cost of heavy fuel oil is evaluated from the following formula [19]:

$$\text{Annual Cost of NG} = \text{Annual NG Consumption} \times \text{NG Price} \qquad (22)$$

Annual Fuel Cost Savings

Annual fuel cost saving can be estimated from the following formula [20]:

$$\text{Saving} = \text{Annual Cost}_{HFO} - \text{Annual Cost}_{NG} \qquad (23)$$

Cost Comparison per Ton of Cement

The cost of each fuel per ton of cement is estimated as shown in the following Equation [20]:

$$Cost\ of\ fuel\ per\ ton\ of\ cement = \frac{\text{Annual cost of fuel}}{\text{Annual Cement production}} \qquad (24)$$

Results and discussion

Gas Molecular Weight (M_a)

Using the collected natural gas compositional data and equation (1), the apparent molecular weight of the gas mixture was determined to be 19.59 g/mol. As presented in Table (1), the gas composition is

dominated by methane and ethane, with trace amounts of other hydrocarbons and acid gases. Consequently, this gas is classified as dry and satisfies the criteria for gas transmission line design.
Gas Gravity (G)
Using the equation (2), the obtained gas gravity (G) value was 0.726 as the following:

$$\mathrm{G} = \frac{19.59}{28.9625} = 0.6767$$

Gas Compressibility Factor (Z)
Using Equations (3,4,5-a,5-b), the pseudo-critical temperature (T_C), pressure (P_C), pseudo-reduced temperature (Tr) and pressure (Pr) were calculated as 382.203 °R and 669.97 psi, 1.38, 0.471 respectively, as presented below:

$$\mathrm{P_C} = 677 + 15 * 0.6767 - 37.5 * 0.6767^2 = 669.97\ \mathrm{Psia}$$

$$\mathrm{T_C} = 168 + 325 * 0.6767 - 12.5 * 0.6767^2 = 382.20\ \mathrm{R^0}$$

$$\mathrm{T_r} = \frac{70 + 460}{382.203} = 1.38$$

$$\mathrm{P_{avg}} = \frac{2}{3}\left(\frac{406.10^3 - 203.05^3}{406.10^2 - 203.05^2}\right) = 315.86\ \mathrm{Psi}$$

$$\mathrm{P_r} = \frac{315.86}{669.97} = 0.471$$

Using the calculated pseudo-reduced temperature (T_r) and pressure (P_r) values, the gas compressibility factor (Z) was estimated at 0.94 based on the Katz and Standing chart [14].

Gas Density (ρ)
By applying equation (7), the estimated value of gas density (ρ) was 1.157 b/ft^3 as presented below:

$$\rho = \frac{315.86 * 19.59}{0.94 * 10.73 * 530} = 1.157\frac{\mathrm{b}}{\mathrm{ft^3}}$$

Gas Viscosity (μ)
The constants K, X, Y in equation (8) were estimated and the obtained values were 107.51, 5.55, and 1.288 as the following:

$$\mathrm{K} = \frac{(9.4 + 0.02 * 19.59)520^{1.5}}{209 + 19 * 19.59 + 520} = 107.51$$

$$\mathrm{X} = 3.5 + \frac{986}{520} + 0.01 * 19.59 = 5.55$$

$$\mathrm{Y} = 2.4 - 0.2 * 5.55 = 1.288$$

Then by substituting the obtained values of K, X, Y constants into equation (8), the value of gas viscosity was then found to be 0.0111 cp as presented below:

$$\mu_g = 107.51 * 10^{-4} e(5.55 * 0.0185^{1.278}) = 0.0111\ cp$$

Results of Pipeline Sizing
Pipe inside Diameter
The pipe inside diameter was calculated based on Weymouth equation (9). The first step for calculating the pipe inside diameter is conducted at the least value of gas inlet pressure which is 20 bar (2000Kpa), the obtained value of pipe diameter was 8.53 inch as the following:

$$16518.16 = 1.42\ \mathrm{d}^{2.67}\left[\frac{2000^2 - 1400^2}{2400 * 0.6767 * 0.94 * 294.26}\right]^{1/2}$$

The obtained diameter above (8.5 in) was tested with the other values of gas inlet pressures by using application software (checalc) online and by comparing the calculated value of gas flow rate obtained by soft application with the requested value by cement factory, the results shown in table 2 below confirmed that size of pipe diameter with 8 in will not be enough to deliver the required value of 14MMSCFD of natural gas needed by cement factory.
The second step, a pipe line with size of more bigger diameter was selected which are 12in, and with the same method followed with 8 in pipe diameter this size of pipe diameter also was tested using application software (che.calc) online to make sure that this size will be enough to deliver the required value gas by cement factory especially at lower value of gas inlet pressure, the obtained results is shown in table 2..Based on the obtained results for pip inside diameter shown in table2, it is clear that the suitable size of pipe inside diameter was 12 in since a pipe line with this diameter will be able to deliver all the required value of gas by cement factory even in the worst cases where the incoming gas Pressure drops to 20 bar.

Table 2: Results of Estimation of pipe line inside diameter by soft application (checalc).

Inlet Pressure (bar)P_1	Outlet Pressure (bar) P_2	Suggested Pipeline Diameter(in)	Calculated Flow Rate (MMSCFD)	Required Gas Flow Rate (MMSCFD)
36	14	8	25.47	14
30	14	8	15.42	14
26	14	8	16.68	14
20	14	8	10.82	14
36	14	12	75.09	14
30	14	12	59.09	14
26	14	12	49.18	14
20	14	12	31.90	14

Results of Gas Velocity in Pipeline

By applying equations 10, 11, the obtained values of entering, outlet and erosional (maximum) gas velocity in pipeline were 7.15 ft/s, 14.3 ft/s, 92.96 ft/s as shown below:
For entering gas velocity, P = P1(avge) =28 bar (406.105psia).

T= T1 = 530 R0, Z = 0.940, D = 12 inch.

Qb = 16518.16m3/hr (14MMSCFD).

$$U1 = 0.002122\left(\frac{14000000}{12^2}\right)\left(\frac{14.7}{520}\right)\left(\frac{0.94*530}{406.105}\right) = 7.15\frac{\text{ft}}{\text{s}} = 2.18\frac{\text{m}}{\text{s}}$$

For outlet gas velocity. P2= 14bar (203.05 psia).

$$U2 = 0.002122\left(\frac{14000000}{12^2}\right)\left(\frac{14.7}{520}\right)\left(\frac{0.94*530}{203.05}\right) = 14.309\frac{\text{ft}}{\text{s}} = 4.36\frac{\text{m}}{\text{s}}$$

For erosional (maximum) gas velocity. $\rho = 1.157\ b/ft3$

$$U_{max} = \frac{100}{\sqrt{1.157}} = 92.96 \text{ ft/s } (28.33 \text{ m/s}).$$

Typically, when the gas stream contains particulate matter such as sand or other impurities, the operational gas velocity should be maintained below 50% of the erosion velocity to mitigate vibration, noise generation, and long-term internal pipe erosion. Upon comparison of the calculated inlet and outlet gas velocities with the erosion velocity, the results confirm that the values remain within acceptable limits.

Results of Pipe Nominal Thickness

The nominal wall thickness of pipe is calculated using Barlow equation 12, the resulted value of thickness was about 5mm as presented below:
Pd = P1avge = 28bar (406.10 psia), D (pipe inside diameter) = 12 inch (304.8mm)
For the Proposed design of pipeline Єw =1.0 for steel pipe seamless Arc weld (SAW or DSAW) [21].
Ft (temperature derating factor) = 1.0 for temperature under 250 F0[21].
The recommended value of corrosion allowance thickness Ca is 1/16 inch (1.58 mm) [21].

The design factor (η) for the proposed design of pipeline is 0.72 for gas lines [21].
δy: Specified minimum Yield strength of pipe (SMYS) is 30000 psia for Pipe with API5L- Grade A-Type ERW- Carbon steel [21].
Specification API 5L Type (seamless Arc weld) is selected according to (ASME B31.8-2016) standard for materials and equipment specification [22].

$$t_{NOM} = \frac{(406.105) * 304.8)}{2 * 1 * 0.72 * 300000 * 1.0} + 1.58 = 4.44\text{mm} \approx 5.0\text{mm}$$

Results of Pipe Schedule Number

The schedule number denotes the pressure rating that the pipe can withstand, and knowledge of this value is required to specify pipe procurement.
using equation 12, the resulted value of schedule number (Sn) of the designed pipe was 13.5 as presented below:
P= P_{1avge} (Gas Interning Pressure) = 406.105 psi, S= SMYS = 30000psi.

$$\text{Sn} = 1000 * \frac{406.105}{30000} = 13.5 \approx 14$$

Results of Reynolds Number and Friction Factor

According to equations 14, 15, the obtained values of Reynolds number and friction factor were 1427.42×10^3, 0.01318 as shown below:

$$N_{Re} = 0.0004778 \left(\frac{14.7}{520}\right)\left(\frac{0.6767 * 14000000}{0.00000745 * 12}\right) = 1427.42 * 10^3$$

The Reynolds number is employed to characterize the flow regime. Since the calculated value exceeds 4000, the gas flow is classified as turbulent, which ensures efficient transport.
For the pipe fraction factor, for carbon steel pipe (non-corroded), ε = 0.001968 [17].

$$f^{0.5} = \frac{1}{2\log\left(\frac{12}{0.001968}\right) + 1.14} \quad , \quad f = 0.01318$$

Results of Gas Pipeline Design Pressures

Maximum Allowable Pipeline Operating Pressure (MAOP)

By applying equation 16, the resulted value of MAOP was 48.86 bar (708.66 psi) as the following:
Design factor for natural gas pipeline (F) = 0.72, For API 5L -Note 2 grade A steel pipes, SMYS of the selected pipe material = 30000 psi [21].

$$\text{MAOP} = 2 * 0.72 \times 30000 \times \frac{5}{304.8} = 708.66 \text{ psia } (48.86 \text{ bar})$$

Pipeline Bursting Pressure (BP)

By applying equation 17, the resulted value of bursting pressure of designed pipe was 108.57 bar (1574.8 psi) as shown below**:**
For API 5L grade A steel pipes, SUTS of the selected pipe material = 48000 psi [21].

$$\text{BP} = 2 * 48000 \times \frac{5}{304.8} = 1574.8\text{psia}(108.57\text{bar})$$

Plastic Collapse Pressure (P_Y)

Based on equation 18, the estimated value of collapse pressure was 67.86 bar 984.25 psia as shown below**:**

$$P_Y = 2 * 30000 \times \frac{5}{304.8} = 984.25\text{psi}(67.86\text{bar})$$

Hydro Test Pressure (H_T)
By applying equation (3.19), the obtained value of maximum hydro test pressure of the designed pipeline (HT) was 885.82 psia (61.075 bar) as presented below:

$$H_T = 1.25 * 708.66 = 885.82\text{psia}(61.075\text{bar})$$

Pressure Drop (ΔP)
Using equation 20, the calculated value of gas pressure drop was 203.05 psi (14bar) as the following:

$$\Delta P = 406.105 - 203.052 = 203.05\text{psia}(14\text{bar})$$

The observed pressure reduction along the pipeline is predominantly attributed to frictional losses. As the resulting pressure drop is within acceptable limits, compressor stations are deemed unnecessary, consequently lowering the operational costs associated with natural gas fuel utilization.
Table 3 below summarizes all the obtained results of the design parameters of pipeline.

Table 3: Results summary of Design Parameters of pipeline.

Parameter	Result
Apparent Gas Molecular weight (M_a)	19.59 g/mol
Gas Gravity(G)	0.6767
Gas deviation factor(Z)	0.940
Gas Density(ρ)	1.157 b_m/ft^3 (0.0185 g/cm^3)
Gas Viscosity(μ)	0.0111 cp
Pipe diameter(D)	12 inch (309.8 mm)
Inlet gas velocity	7.15ft/s (2.18m/s)
Out let gas velocity	14.309 ft/s (4.36m/s)
Erosional (maximum) gas velocity	92.96 ft/s (28.33 m/s)
Pipe thickness(t)	0.1968 inch (5 mm)
Schedule Number	14.0
Reynolds number (N_{Re})	1427.42×10^3
Pipeline Maximum Allowable Operating Pressure	708.66 psi (48.86 bar)
Pipeline Bursting Pressure (BP)	1574.8 psi (108.57 bar)
Plastic collapse pressure ($P_{Y)}$)	984.25 psi (67.86bar)
Pipeline Hydro Test Pressure (H_T)	885.8 psi (61.075 bar)
Pressure Drop (Δp)	203.05psi (14bar)

Results of Economic Evaluation of Consumption of Heavy Fuel Oil and Natural Gas
Results of Annual Cost of Heavy Fuel Oil (HFO)
By applying the equation (3.21), the resulted value of annual cost of heavy fuel oil was 52.09 Million USD /year as shown below:

HFO price = 400 USD / ton [23].

Annual Cost of HFO = 130229 ×400 = 52091600 USD/year = 52.09 Million USD/year.

Results of Annual Cost of Proposed Natural Gas (NG)
According to equation.22, the estimated value of Annual Cost of Natural Gas (NG) was 14.81 Million USD / year as shown below:
Natural gas heating value = $36MJ/m^3$ Daily consumption of gas volume = 396435m^3/day Energy of natural gas (ENG) = Gas volume × Natural Gas Heating Value
Daily Energy gained by natural gas = 396435 ×36 = 14271660 MJ / day
Annual Energy gained by natural gas = 14271660 ×365 = 5.209×109 MJ/year
Conversion factor**:** 1MM Btu = 1055.06 MJ [23].

Annual Energy gained by gas in MM Btu = $\frac{5.209\times10^9}{1055.06}$= 4937165 MM Btu/year

Natural gas price = 3 USD/MM Btu [52].

Therefore, Annual Cost of NG = 4937165 ×3 = 14811495 USD/year =14.81 Million USD/year.

Results of Annual Fuel Cost Savings

By applying of equation 23, the obtained value of fuel cost saving was 37.28 Million USD / year as below**:**

Saving =52.09 – 14.81 = 37.28 Million USD / year.

Results of Cost Comparison per Ton of Cement

According to equation 24, the estimated values of cost per ton of cement for heavy fuel oil and natural gas were 52.09 USD /ton cement and 14.81 USD / ton cement as shown below:

For Heavy fuel oil:

$$\frac{cost}{ton\ cement} = \frac{52091600}{1000000} = 52.09\ \mathrm{USD/ton}$$

For Natural Gas:

$$\frac{\mathrm{cost}}{\mathrm{ton\ cement}} = \frac{14811495}{1000000} = 14.81\mathrm{USD/ton}$$

Table 4 below summarize the resulted values of fuel economic evaluation.

Table 4: Results Summary of Fuel Economic Evaluation.

Parameter	Heavy Fuel oil	Natural Gas
Annual Fuel consumption	130229 ton /year	14 MM SCFD
Annual fuel cost	52.09 Million USD	14.81 Million USD
Cost per ton of cement	52.09 USD /ton	14.81 USD /ton
Annual saving	_	37.28 Million USD

Based on the given fuel prices, Annual fuel costs decrease from approximately 52.09 million USD to 14.81 million USD, Annual savings reach approximately 37.28 million USD, the fuel cost per ton of cement decreases by about 71.6%. The results indicate that replacing heavy fuel oil with natural gas at the Souk Al-Khamis cement plant is highly advantageous. Natural gas offers substantial economic benefits including lower annual fuel costs, greater cost savings, and reduced fuel cost per ton of cement while also providing environmental advantages through lower emissions and cleaner combustion.

Conclusion and Recommendations

Conclusion

The present study addresses the design of an integrated natural gas pipeline for fuel supply to the Souk Al-Khamis cement plant. The design procedure incorporated equations derived from ASME and API codes and standards to determine the pipe diameter, wall thickness, schedule number, and pressure rating. The resulting design parameters obtained include a 12-inch inside diameter, 5-mm wall thickness, Schedule 14, and a maximum allowable operating pressure of 48.86 bar. Based on the obtained results, the following points could be concluded:

1. The selected a pipe with a diameter of 12 inches will ensure a stable flow that meets the cement plant kiln requirements at a safe operating pressure and gas velocity within internationally permissible limits.
2. The transition from Heavy Fuel Oil to natural gas represents an important step toward improving industrial efficiency and lowering operational costs in the cement industry.
3. Natural gas pipeline systems are technically feasible, economically beneficial, and environmentally sustainable for industrial applications in Libya.

Recommendations

Based on the obtained results of this study, the following recommendations are proposed:

1. Applying of an appropriate simulation programs to simulate the designed pipe line to make sure that all the obtained design parameters are converged with simulation process and for more accurate hydraulic analysis and optimization.
2. The proposed gas transmission pipeline project for Souk Al-Khamis cement plant should be considered for future implementation due to its strong technical and economic advantages.

3. Cement plants in Libya should gradually transition from Heavy Fuel Oil to natural gas to reduce operating costs and environmental pollution.

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