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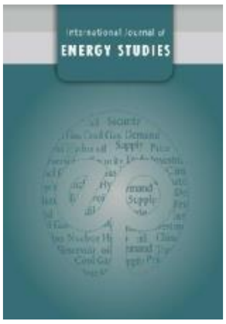

Research Article

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Cost Analysis of Inhibitive Drilling Fluids

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Highlights

- Inhibitive drilling fluid cost of an oil well was calculated.
- Additive used in the drilling fluid, personnel expense, transportation and waste management costs were calculated and compared with each other.
- Cost of the drilling fluid used in various well diameters was calculated.
- Cost per feet and cost per barrel of the drilling fluid were calculated.

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ABSTRACT

The main objective of this study is to provide a better understanding of inhibitive water-based drilling fluid's central cost drivers. In this study a comparison of costs is provided between two polymer drilling fluid systems used to drill an oil well located in Hungary. In order to deliver fair cost analysis, several factors were considered that contribute to the overall drilling fluids costs, such as products, preparation, equipment, waste management, transportation, personnel, cost per foot drilled, and cost per barrel of the muds. Analysis results reflects on that the change of mud systems differentiates the costs, and also the expenses heavily depend on the consumed products, personnel, and utilized equipment. Other noticeable points which have been concluded from the study are that the cost per foot of KCl/Gypsum/Polymer is € 3.6 higher than the cost per foot generated by gypsum/polymer mud. Moreover, 42% of the total mud costs is given by the first drilled section of the well, while the second section constitutes 58%. Consequently, the overall cost of the mud used in the well was estimated as € 76,797.25 considering all the factors and well diameter. Finally, this research presents a statistical analysis that can be used as a reference for the subsequent perspective wells intended to be drilled at the same field.

Keywords: *Drilling fluid, Cost, Data, Inhibitive, Drilling*

1. INTRODUCTION

Global energy demand is increasing due to population growth and growing economies. Today, up to 80% of this energy need is obtained from fossil resources (oil, gas and coal). It is predicted that the dependence on these resources will continue to a great extent for the next 25 years, as can be seen in Table 1. Increasing need for energy, the limited amount of fossil fuels, their serious impact on the environment and depletion reveal the necessity of alternative energy sources. However, since this energy source requires large investments and its efficiency is low, investments can be made mostly by developed countries. Therefore, renewable energy is expected to reach levels that will only meet 20% of the total energy need by 2045 and it is estimated that oil and gas will constitute the highest rate in energy production over the next 25 years [1]. Since this will be possible with the performing high-cost drilling operations, there is great need to study the parameters affecting the drilling cost in detail.

Table 1. Total primary energy demand by fuel type, 2019–2045 [1].

	Levels (mboe/d)						Growth (mboe/d)	Fuel share (%)	
	2019	2025	2030	2035	2040	2045	2019-2045	2019	2045
Oil	91.0	94.4	97.7	99.3	99.7	99.5	8.5	31.5	27.5
Coal	77.1	75.1	75.1	74.3	72.8	71.0	-6.1	26.7	19.7
Gas	66.9	69.8	76.2	82.2	87.3	91.2	24.3	23.1	25.3
Nuclear	14.4	16.1	17.5	19.1	20.8	22.1	7.7	5.0	6.1
Hydro	7.3	8.1	8.8	9.5	10.2	10.5	3.2	2.5	2.9
Biomass	26.4	28.9	31.0	32.9	34.6	35.5	9.1	9.1	9.8
Other renewables	6.0	10.6	15.5	20.8	26.8	31.4	25.4	2.1	8.7
Total	289.1	303.0	321.9	338.1	352.3	361.3	72.1	100.0	100.0
mboe/d	thousands of barrels of oil equivalent per day								

General economics of drilling projects involve the study of costs, expenses and profit related to the project. Drilling cost estimation and optimization are important aspects of success of a drilling project [2-5]. The majority of the costs of drilling a well depends on the depth of the well and the type of formation, the drilling time and the casing and cementing of the well. On the other hand, drilling costs are also affected by other items such as engineering studies, drilling and field consultancy services, material procurement, logistics, well tests, possible evacuation operations [3], [6]. Apart from these, one of the most important items affecting the cost of drilling operation is drilling fluid.

A typical drilling fluid consists of a mixture of water, clay and a number of chemicals. Its main task is to clean the borehole by transporting drilling cuttings from the bottom of the well to the surface, to reduce the abrasion by lubricating and cooling the drill string and drill bit, to ensure the stability of the well by controlling the pressures , and to keep the drill cuttings in the annulus in suspension when the circulation is interrupted, and to prevent the mechanical or differential sticking problems that may occur [6-10].

Different types and compositions of drilling mud are used in oil, gas and geothermal drilling [9, 11, 12, 13]. The main types of drilling mud used are determined by the depth of the well and the drilled formation. The additives to be used in the formulated drilling mud are determined based on their interaction with the drilled formation,. Drilling fluid must have a certain density, rheological, fluid loss and filter cake properties [7-8]. The drilling fluid is formed by mixing many different chemicals in certain proportions in order to achieve these properties and perform the desired tasks [10, 14-17]. Additives commonly used in water-based drilling fluids was given in Table 2.

Drilling fluid is divided into three main classes, water-based, oil-based and air-based, according to the phase type and chemical properties that forms its content. Water-based fluids are the most widely used type of drilling fluid, as they are inexpensive, easily available, and can overcome most drilling problems. Inhibitive drilling fluid is one of the type of water based drilling fluid. Systems such as gypsum mud, lime mud, potassium/polymer mud, glycol mud are some of the inhibitive mud types. The inhibitive water-based muds have many advantages such as inhibiting the swelling and dispersion of clays, tolerating high drilled solids content showing low rheology and gels with a very good mud shape, resisting to anhydrite contamination. It is a very stable system and easy for maintenance due to its easy formulation, and very easy to flocculate so reducing waste liquid to dispose. It can be weighted up to a density of 2.2 – 2.4 sg, and it is resistant to salt contamination. These properties of this kind of system help to increase wellbore stability, improve rate of penetration and does not have environmental restrictions for disposal [7, 8, 18].

As it is well known, shales comprise 75% of the drilled formations and may generate serious wellbore stability problems during drilling when exposed to conventional drilling mud [6], [19, 20]. Water based inhibitive muds have been used to minimize these problems during the drilling of wells with excessive chemical and physical reactions between mud-formation and well stability problems. Inhibitive muds used in active wells, which contain structures such as gypsum, anhydrite, salt, and shale, minimize the interaction between the formation and mud, thus ensuring a more efficient drilling process and reducing drilling problems [21-23]. Inhibitive muds can achieve this by chemical or mechanical inhibition.

Table 2. Additives commonly used in water-based drilling fluids (Derived from Rabia, H. [9]).

Fluid loss controller	Bentonite, polymers, starches and thinners or deflocculants (PAC, CMC etc.)
Weighting	Barite, haematite, galena, magnetite, siderite
Thinners	Plant tannins, lignitic materials, lignosulfonates, low molecular weight, synthetic, water soluble polymers.
Viscosifiers	Bentonite, xanthan gum, guar gum, synthetic polymers, resins, silicates
Alkalinity and pH control materials	$NaOH$, KOH, $Ca(OH)_2$, $NaHCO_3$ and $Mg(OH)_2$
Lubricating material	Oil, surfactants, fatty alcohol, graphite, asphalt, gilsonite, and polymer or glass beads
Shale stabilizing materials	Polyacrylics, asphaltic hydrocarbons, potassium and calcium salts, glycols, and certain surfactants and lubricants.
Lost circulation material	Granules, fiber, flake
Emulsifier	Lignosulfonate, lignite, detergent
Special Additives	Flocculants, defoamers

Drilling fluid plays a crucial role in the rate of penetration and can reach approximately 15 to 18% of the total drilling costs [14]. Drilling fluid also affects the total well cost indirectly in many ways. A proper formulated drilling mud can contribute to the profit of the well by raising rate of penetration, mitigation of reservoir damage, circulation loss and stabilizing wellbore against formation pressure [8].

It is important to better understand and evaluate the project bid prices based on the impact of drilling fluid parameters on project costs for the owners and contractors and to determine whether the drilling mud systems developed for researchers are economical or not. However, there is neither adequate data on the drilling mud cost nor a published document investigating the parameters affecting the drilling mud cost. Okoro et al. [24] presented cost data for spud, KCl and pseudo oil base muds solely considering product used in the drilling fluids.

The aim of this study is to analyse cost of the water based inhibitive drilling fluids while the hole is being drilled and to provide useful information to the drilling industry about project costs incurred by drilling fluid on the drilling market. In the study, an oil well at a depth of 6,233.6 ft and located in Hungary was investigated in detail. Gypsum/Polymer and KCI/Gypsum/Polymer inhibitive drilling mud systems were used in the two different depth intervals from 78.740-3,100.4

ft and 3,100.4-6,233.6 ft by using 12 1/4" and 8 1/2" bit diameter, respectively. The cost analysis of these drilling muds was studied considering the factors from the products used in the preparation of mud, equipment used in mud cleaning, management of waste mud, transportation and expenses of personnel in charge. To the best of author's knowledge, this is the first approach to study cost analysis of water based inhibitive drilling fluids extensively.

2. WELL DESCRIPTION

Initially, drilling mud data from daily drilling reports of an oil well located in Northern Hungary were gathered. After the quality control of the data, the necessary data for the study was extracted and calculations were made for each item based on the exchange rate in 2018. In the study, cost analysis of the drilling fluid was performed taking into account the factors from the products used in the preparation of mud, equipment used in mud cleaning, management of waste mud, transportation and expenses of personnel in charge. Detailed information of these categories has been presented in the sections below. In Figure 1, schematic of the well for 12 1/4-in and 8 1/2 in hole section where gypsum/polymer mud and KCl/gypsum/polymer mud were used, respectively can be seen.

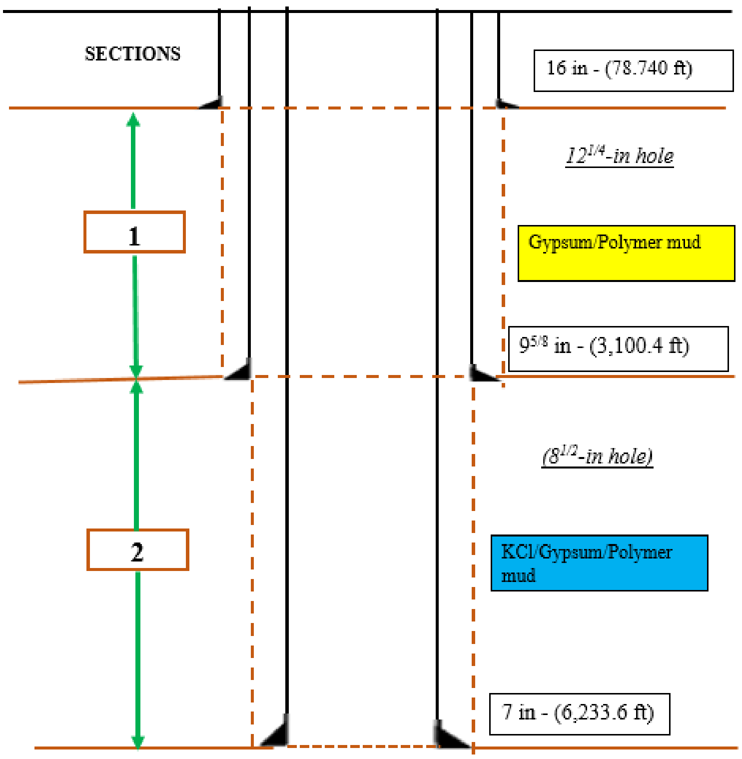

Figure 1. Schematic of the well (for 12 1/4-in and 8 1/2-in hole section where gypsum/polymer mud and KCl/gypsum/polymer mud were used, respectively)

2.1. Mud parameters and materials

Drilling from 78.740 ft to 3,100.4 ft (first section) was drilled with the use of gypsum-polymer mud system and bit 12 1/4" diameter. This system was designed to provide inhibition while drilling water-sensitive shales. It also provided the appropriate rheology to ensure that the hole was adequately cleaned. The Gypsum mud systems have many advantages such as partially inhibiting the swelling and dispersion of clays, increasing wellbore stability, improving rate of penetration, tolerating high low gravity solid content showing low rheology and gels with a very good mud shape. And, they are very stable system and easy for maintenance due to its easy formulation.

In the second section (from 3100.4 ft 6233.6 ft), mud from previous section was cleaned by floc unit and converted to KCl-Gypsum-Polymer mud system. The system provided a fluid with the appropriate rheology to ensure that the hole is adequately cleaned and the necessary inhibition is obtained to control the shale. Properties of gypsum-polymer mud and KCl-Gypsum-Polymer mud could be seen in Table 3 and the volume of each drilling fluid system was given in Table 4. Also, the products employed in the formulation of gypsum-polymer mud and KCl-Gypsum-Polymer mud system was presented in Table 5 and Table 6, respectively.

Table 3. Properties of the drilling fluids for each section

Mud parameters	**Unit**	**I.**	**II.**
Type of fluid	-	Gypsum-Polymer	KCl-Gypsum-Polymer
Density	kg/dm^3	1.10-1.14	1.10-1.14
Marsh Viscosity	sec/l	46-62	44-60
Plastic viscosity	cP	(12-22)	(15-22)
Yield Point	$lb/100ft^2$	18-30	14-25
Gel 10 sec.	$lb/100ft^2$	4-8	3-6
Gel 10 min	$lb/100ft^2$	6-20	6-18
API Filtrate	$cm^3/30'$	<6	<5
Cake thickness	mm	1.0	0.5-1.0
pH	-	8.5-9.5	>10.0
Ca++	mg/l	1000-1600	1000-1600
Cl-	mg/l	<2000	16000-22000
Gypsum excess	kg/m^3	15-20	15-20
Sand	% Vol	<1	TR
Total solid	% Vol	2-5	3-10
LGS (drilled solids)	% Vol	2.5-4.9	3.6-6.4

Table 4: Mud volume estimate for section 1 and section 2

Section 1		12 1/4" hole (10% washout) volume		8 1/2" hole (10% washout) volume		
Description		m^3	bbl		m^3	bbl
Casing	csg 16"	3	18	csg 9 $^{5/8}$"	38	238
Open hole	12 $^{1/4}$" hole	85	535	8 $^{1/2}$" hole	42	267
Surface volume	Rig pits	80	503	Rig pits	80	503
Dilution	New mud	196	1231	New mud	102	642
Required mud volume		364	2287		262	1650

Note: Fluid volume doesn't take in consideration losses in formation.

Table 5: Quantity of materials for gypsum/polymer mud

Product	**Packaging**	**Total consume (Ton)**
Caustic soda	25 kg sacks	0.325
Viscosifier-1	1000 kg big bags	6.000
Gypsum	25 kg sacks	9.100
Bactericide	200 kg drums (208 lt)	0.400
Defoamer	180 kg drums (208 lt)	0.360
Secondary fluid loss controller	25 kg sacks	2.525
Viscosifier-2	25 kg sacks	0.25000
Corrosion inhibitor	200 kg drums (208 lt)	0.400
Viscosifier-3	25 kg sacks	0.750
Lubricant	170 Kg drum (208 lt)	3.230

Table 6: Quantity of materials for KCl/Gypsum/Polymer mud

Product	**Packaging**	**Total consume (Ton)**
Caustic soda	25 kg sacks	0.225
Gypsum	25 kg sacks	4.800
Bactericide	200 kg drums (208 lt)	0.400
Defoamer	180 kg drums (208 lt)	0.360
Secondary fluid loss controller	25 kg sacks	1.050
Viscosifier-2	25 kg sacks	0.425
Corrosion inhibitor	200 kg drums (208 lt)	0.400
Lubricant	170 Kg drum (208 lt)	2.040
Primary fluid loss controller	25 kg sacks	1.650
Potassium Chloride	1000 kg big bags	8.000
Lost circulation material	25 kg sacks	4.350
Viscosifier-3	25 kg sacks	0.275

2.2. Solids control

Effective solids control process is a fundamental to suitable mud control [25]. Most of the mud treatment cost can be directly attributed to the buildup of drilled solids and it is almost always cheaper to remove these solids than to combat them with chemicals. A good solids control system has the potential to reduce mud costs and to provide consistency of mud properties which will be reflected in better hole conditions and well stability [26]. In this study, two section of hole shale shakers were used to handle the flow rate and volume of cuttings that would be generate. Since shale shakers could not remove silt and colloidal-size solids centrifuges were used to control ultra-fine drilled solids. As well-known some dilutions are usually made to decrease mud colloid content. In fact, colloids are not mechanically removable with any equipment because they are too small. Therefore, flock unit was used to remove colloids with chemical reaction. A special chemical makes colloid flocculate and a polyelectrolyte induces coagulation in big flakes that can be removed using a high G-force in a centrifuge. From centrifuging two flows are gained: a solid one discharged trough conveyor to the corral to be disposed and the liquid one that can be used to build up new mud or reintroduced directly in circulation. Equipment used, their number and the unit cost of each equipment for 12 1/4" and 8 1/2" well section were presented given in Table 7.

Table 7. Unit cost and number of equipment for the 12 1/4" and 8 1/2" well section

Equipment	Price/unit	12 1/4" hole (10% washout)	8 1/2" hole (10% washout)
Centrifuge #1	240.00	5	10
Centrifuge #2	240.00	5	10
Flock unit	125.00	5	10
Mud cabin	30.00	5	10

2.3. Waste management process

Waste management was performed by the use of flock unit that contributes to minimize waste liquid reducing dilution water. Gypsum system can be easily flocculated with a cationic flocculants. The flock unit should be run while drilling recovering the centrifuge overflow directly to the active system. An accurate set up of centrifuge and flock unit should be done in order to be sure that the overflow doesn’t contain any flocculants excess. Mud volume treated for each well section was shown in Table 8.

Table 8. Unit cost and amount of treated volume of the muds for the 12 1/4" and 8 1/2" well section

Waste management	Unit	Price/Unit	12 1/4" hole (10% washout)	8 1/2" hole (10% washout)
Treated volume	m^3	15.00	80.00	130.00

2.4. Services

Services of the mud compose of personnel and transportation categories. Unit cost of personnel and transportation and their number for each well section were given in Table 9 and Table 10, respectively.

Table 9. Unit cost and number of personnel for the 12 1/4" and 8 1/2" well section

Personnel	**Price/unit**	**12 1/4" hole**	**8 1/2" hole**
Drilling Fluids- Engineer 1	425.00	5	10
Drilling Fluids- Engineer 2	400.00	5	10
Solid Control- Engineer 1	325.00	5	10

Table 10. Unit cost and number of transportation for the 12 1/4" and 8 1/2" well section

Transport	**Price/unit**	**12 1/4" hole (10% washout)**	**8 1/2" hole (10% washout)**
Transport Lab Cabin	750.00	-	-
Transport Flock unit	750.00	-	-
Transport centrifuges	750.00	-	-
Transport contingency material	750.00	-	-
Transport material	750.00	1	1

3. RESULTS AND DISCUSSION

In the following section analysis of drilling mud cost factors for 12 1/4" and 81/2" was presented.

3.1. Cost analysis of drilling fluid for 12 1/4" section

Before proceeding to this stage, the 16-inch casing was lowered down and cemented. Gypsum/polymer mud prepared in 2287 bbl volume was used as the drilling fluid type throughout the section, as can be seen from the Table 4. Viscosifiers, fluid loss controllers, bactericide, deformer, lubricant, gypsum, corrosion inhibitor and caustic soda additives were used to maintain the rheological properties of the drilling fluid during the preparation and circulation. Table 11 shows the cost of each additive used in the formulation of the gypsum/polymer mud and the total cost results of the additives for the $12^{1/4}$" well section. The total cost of the additives used was calculated as € 21,171.25. In addition, while lubricants had the highest cost of additives with € 6,783, caustic soda had the least cost with € 325.

Table 12 shows the results of equipment, personnel, waste management and transportation costs, which are other factors that affect the drilling mud cost in section 12 $^{1/4}$". As can be seen from the table, personnel expense constituted the second-ranked cost item after additives with € 5,750 and cost of equipment, waste management and transportation were calculated as € 3750, € 1250 and € 750, respectively.

Table 11. Price of products for gypsum/polymer mud

Product	**Price (€/Ton)**	**Total Price (€)**
Caustic soda	1,000.00	325.00
Viscosifier-1	220.00	1,320.00
Gypsum	220.00	2,002.00
Bactericide	2,100.00	840.00
Defoamer	3,550.00	1,278.00
Secondary fluid loss controller	2,150.00	5,428.75
Viscosifier-2	2,900.00	725.00
Corrosion inhibitor	1,300.00	520.00
Viscosifier-3	2,600.00	1,950.00
Lubricant	2,100.00	6,783.00
	TOTAL	**21,171.75**

Table 12. Price of equipment, personnel, waste management and transportation for gypsum/polymer mud

Equipment	**Total Price (€)**
Centrifuge #1	1200.00
Centrifuge #2	1200.00
Flock unit	625.00
Mud cabin	150.00
TOTAL	**3,175.00**
Personnel	**Total Price (€)**
Drilling Fluids- Engineer 1	2,125.00
Drilling Fluids- Engineer 2	2,000.00
Solid Control- Engineer 1	1,625.00
TOTAL	**5,750.00**
Waste management	**Total Price (€)**
Treated volume (m^3)	1,200.00
TOTAL	**1,200.00**
Transport	**Total Price (€)**
Transport Lab Cabin	0
Transport Flock unit	0
Transport centrifuges	0
Transport contingency material	0
Transport material	750.00
TOTAL	**750.00**

In addition, the percentage ratios of each additive used in the gypsum/polymer drilling mud formulation and of all the items that affect the drilling mud cost were analysed and the relevant results were given in the Figure 2. In this hole section with gypsum/polymer mud system, lubricant and fluid loss control additives accounted for the highest percentage rate among other additives used, with 32.04% and 25.64%. On the other hand, caustic soda (alkalinity controller) constitutes lowest percentage rate with 1.54%.

When the percentage rates of the cost items were compared among themselves, crucial differences were found among the drivers. While the additives used for gypsum/polymer mud in the 12 $^{1/4}$" well section constituted the highest expense with a rate of 66%, personnel and equipment used in drilling mud cleaning constituted 18% and 10% of the cost, respectively. Also, it should be noted that drilling mud transportation and waste management expenses constituted the lowest share with rates of 2% and 4%.

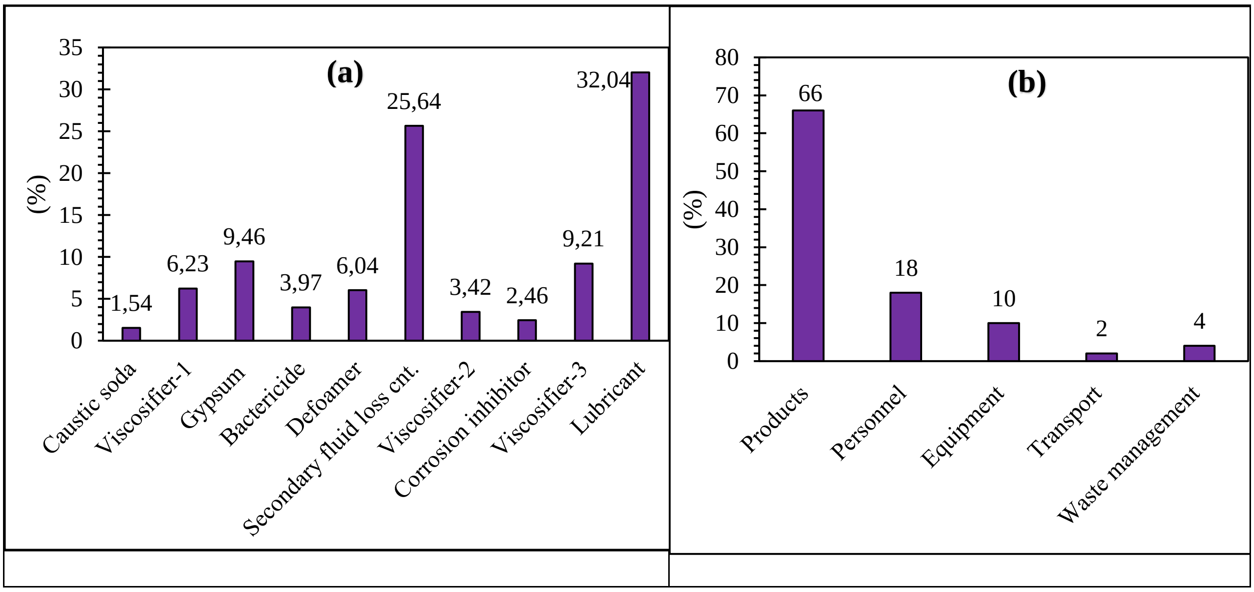

Figure 2. Cost percentage of 12 1/4" section (a) for each products (b) for total products, personnel, equipment, transport and waste management

3.2. Cost analysis of drilling fluid for 8 1/2" section

Before proceeding to this stage, the 9 5/8" casing was lowered down and cemented. When the cost items in this section are examined, it was observed that additives, equipment and personnel expenses are greater than those of 12 1/4" well section, although the order of expense items in the section of $8^{1/2}$" is as in section of 12 1/4". Table 13 shows the cost of each additive and total cost of the additives used in the formulation of the KCl/gypsum/polymer mud. From the table, it is seen that caustic soda, gypsum, bactericide, defoamer, corrosion inhibitor, lubricant, potassium chloride, viscosifier and fluid loss control agents were used as mud additives in the preparation of the KCl/gypsum/polymer mud in this section and the total cost of drilling mud additives in the well section of 8 1/2" was calculated as € 24,200.50. It should also be noted that the cost of fluid loss controllers, lubricant and potassium chloride additives was calculated as € 8,527.50, € 4,284.00 and € 4,000.00 respectively, and these additives were determined as the 3 additives with the highest cost compared to other additives. On the other hand, cost of the caustic soda was calculated as € 225.00 and it was seen that it was the lowest cost additive, as in the 12 1/4" well section.

Table 13. Price of products for KCl/gypsum/polymer mud

Product	**Price (€/Ton)**	**Total Price (€)**
Caustic soda	1,000.00	225.00
Gypsum	220.00	1,056.00
Bactericide	2,100.00	840.00
Defoamer	3,550.00	1,278.00
Secondary fluid loss controller	2,150.00	2,257.50
Viscosifier-2	2,900.00	1,232.50
Corrosion inhibitor	1,300.00	520.00
Lubricant	2,100.00	4,284.00
Primary fluid loss controller	3,800.00	6,270.00
Potassium Chloride	500.00	4,000.00
Lost circulation material	350.00	1,522.50
Viscosifier-3	2,600.00	715.00
	TOTAL	**24,200.50**

Table 14 demonstrates results of equipment, personnel, waste management and transportation cost for KCl/gypsum/polymer mud. Personnel and equipment expenses were calculated as € 11,500.00 and € 6,350.00, respectively, and as in the section of 12 1/4", after the expenses of additives with € 24,200.50, they constituted the other items of the highest cost arising from drilling mud. On the other hand, waste management and transportation of KCl/gypsum/polymer mud were estimated as € 1,950.00 and € 750.00 respectively, as can be seen from the table.

Percentage ratios of each additive used in the preparation of KCl/gypsum/polymer mud and all relevant parameters affecting the cost of the mud were analysed in the 8 1/2" well section and the results were given in Figure 3. When the percentage ratios of the additives used in the preparation of KCl/gypsum/polymer mud were examined among themselves, it was seen that the fluid loss control additives, lubricant and potassium chloride constituted the highest percentage compared to the other additives used with 35.24%, 17.7% and 16.53%, respectively. On the other hand, it was also seen that as in the 12 1/4"section, caustic soda had the lowest share with 0.93%.

Table 14. Price of equipment, personnel, waste management and transportation for KCl/gypsum/polymer mud

Equipment	**Total Price (€)**
Centrifuge #1	10
Centrifuge #2	10
Flock unit	10
Mud cabin	10
TOTAL	**6,350.00**
Personnel	**Total Price (€)**
Drilling Fluids- Engineer 1	10
Drilling Fluids- Engineer 2	10
Solid Control- Engineer 1	10
TOTAL	**11,500.00**
Waste management	**Total Price (€)**
Treated volume	130.00
TOTAL	**1,950.00**
Transport	**Total Price (€)**
Transport Lab Cabin	-
Transport Flock unit	-
Transport centrifuges	-
Transport contingency material	-
Transport material	1
TOTAL	**750.00**

When the items affecting the cost of KCl/gypsum/polymer mud are evaluated, it was observed that while percentage cost of products consumed in the 12 1/4" section, which was 66%, higher than that of 8 1/2" section, which was 54% and the percentage cost of equipment and personnel for 8 1/2" section is greater than those of first section. This could be resulted from more solid amount exist in the KCl/gypsum/polymer mud system. Cost of the equipment, waste management and transportation of the KCl/gypsum/polymer mud was determined as 26%, 14%, 4%, 2%, respectively.

Figure 4 shows the total cost results for each well section, taking into account all relevant factors that affect the drilling mud cost. From the figure, it was seen that the highest mud cost was at 8 1/2" section when the consumed product, personnel in charge, equipment utilized, transportation and waste management of the fluid were considered, and while the ratio of the mud cost used during this section to the total mud cost was determined as 58%, the ratio of the mud cost to total mud cost in 12 1/4" section was determined as 42%.

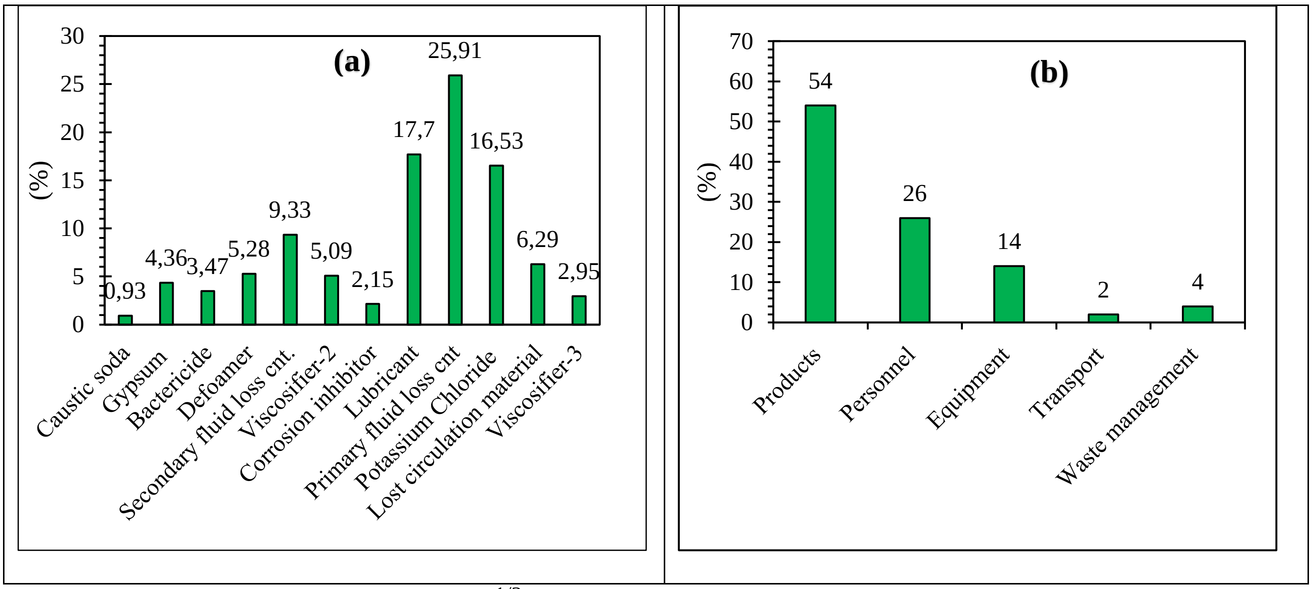

Figure 3. Cost percentage of $8^{1/2}$" section (a) for each products (b) for total products, personnel, equipment, transport and waste management

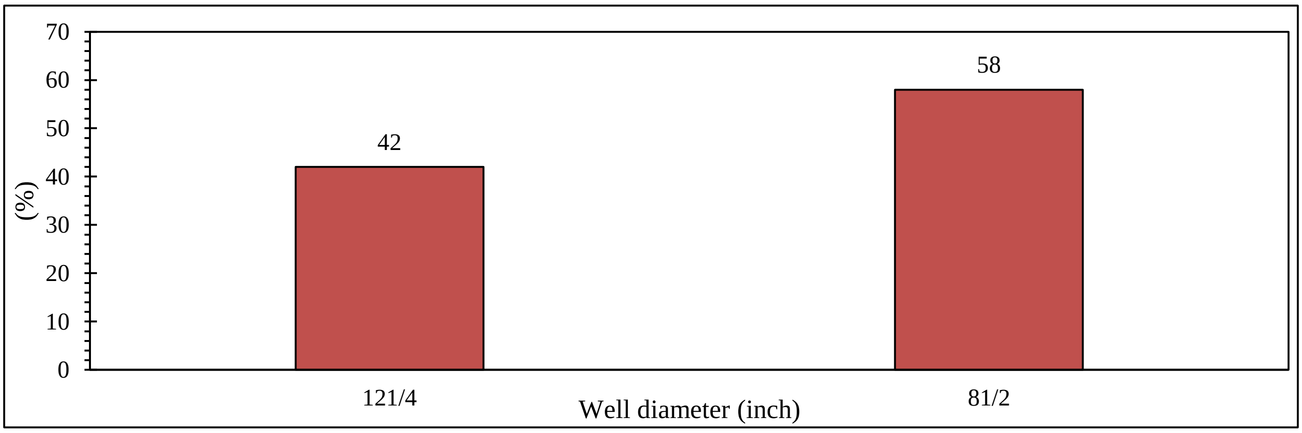

Figure 4. Percentage of well section costs in total mud cost

3.3. Total Cost analysis of drilling fluid

A total of 3,937 bbl of mud was prepared throughout all stages of the 6233.6 ft deep borehole. As a result of the calculations, the total cost of mud additives used until the end of the drilling operation was determined as € 45,372.25 (Table 15). It worths to stated that while the most costly of the additives used in the relevant borehole were fluid loss controller and lubricant additives with € 13,956.25 and € 11,067.00, respectively, the lowest cost additives were determined as soda ash and corrosion inhibitor additives with € 550.00 and € 1,040.00. On the other hand, total cost of the equipment utilized, personnel, waste management and tranportation of drilling fluid used in the entire well was determined as € 9,525.00, € 17,250.00, € 3,150.00 and € 1,500.00, respectively (Table 16).

Table 15. Price of drilling fluid's products for the entire well

Product	Price (€/Ton)	Total Price (€)
Caustic soda	1,000.00	550.00
Viscosifier-1	220.00	1,320.00
Gypsum	220.00	3,058.00
Bactericide	2,100.00	1,680.00
Defoamer	3,550.00	2,556.00
Secondary fluid loss controller	2,150.00	7,686.25
Viscosifier-2	2,900.00	1,957.50
Corrosion inhibitor	1,300.00	1,040.00
Viscosifier-3	2,600.00	2,665.00
Lubricant	2,100.00	11,067.00
Primary fluid loss controller	3,800.00	6,270.00
Potassium Chloride	500.00	4,000.00
Lost circulation material	350.00	1,522.50
	TOTAL	**45,372.25**

Table 16. Price of drilling fluid's equipment, personnel, waste management and transportation for the entire well

Equipment	**Total Unit**	**Total Price (€)**
Centrifuge #1	15	3,600.00
Centrifuge #2	15	3,600.00
Flock unit	15	1,875.00
Mud cabin	15	450.00
	TOTAL	**9,525.00**
Waste management	**Total Unit**	**Total Price (€)**
Treated volume (m^3)	210.00	3,150.00
	TOTAL	**3,150.00**
Personnel	**Total Unit**	**Total Price (€)**
Drilling Fluids- Engineer 1	15	6,375.00
Drilling Fluids- Engineer 2	15	6,000.00
Solid Control- Engineer 1	15	4,875.00
	TOTAL	**17,250.00**
Transport	**Total Unit**	**Total Price (€)**
Transport Lab Cabin	0	0.00
Transport Flock unit	0	0.00
Transport centrifuges	0	0.00
Transport contingency material	0	0.00
Transport material	2	1,500.00
	TOTAL	**1,500.00**

When the total product consumption was analysed, it was seen that the fluid loss controller and lubricant had the highest percentage rate among other materials with 30.36% and 24.39%, respectively, as can be seen in the Figure 5. On the other hand, the caustic soda and corrosion inhibitor additives had the lowest percentage rate with 1.21% and 2.29%. From the figure, it was also seen that total percentage of product, personnel, equipment, transport and waste management of the drilling fluid used in entire well were 59%, 23%, 12%, 2%, 4%, respectively.

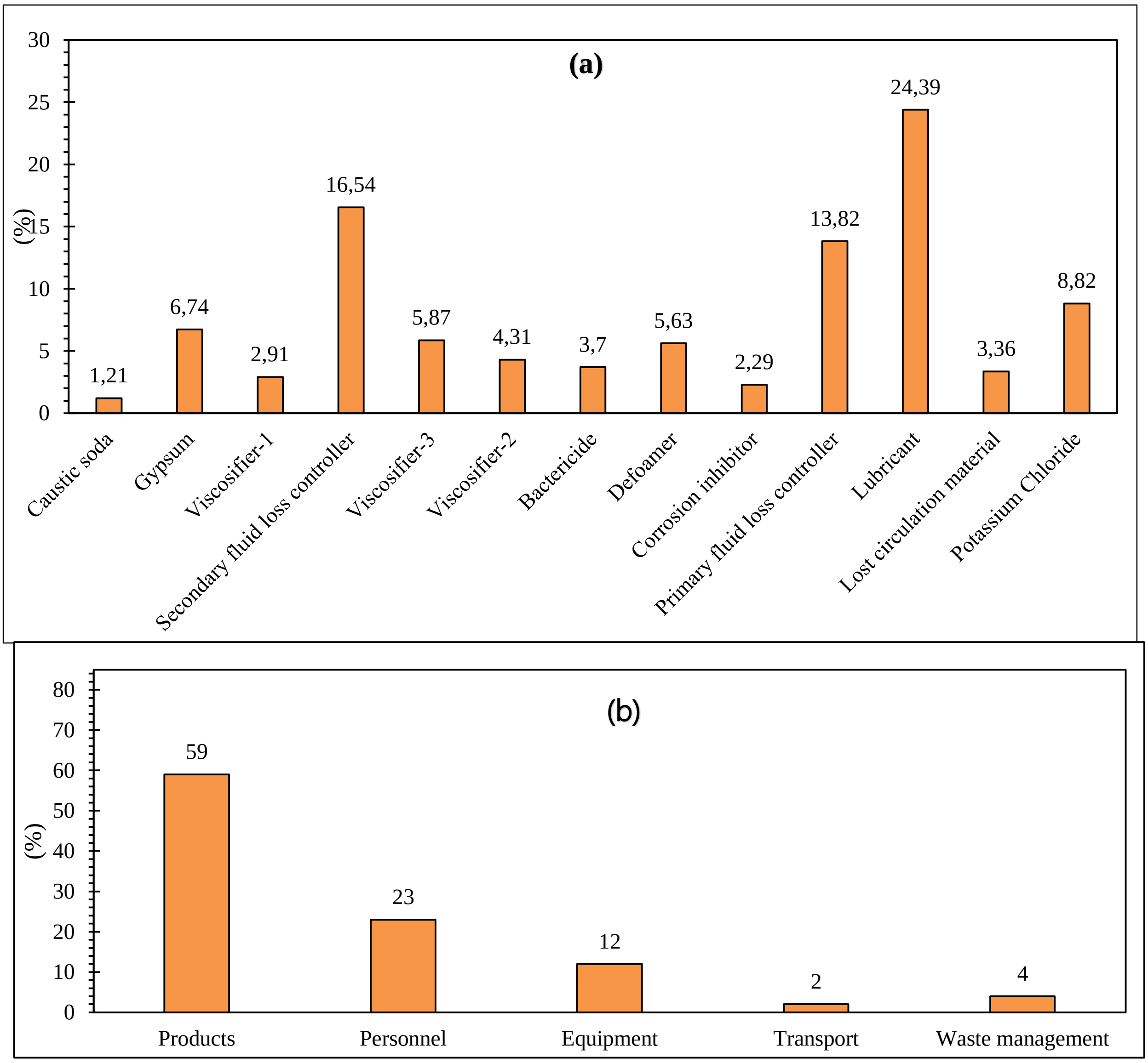

Figure 5. Total ratio of each factors in the entire well (a) for each products (b) for total products, personnel, equipment, transport and waste management

The total cost of drilling mud until the end of the drilling process was determined as € 76,797.25, as a result of considering all the additives used in the preparation, equipment used in the cleaning, the personnel in charge, the waste management and transportation of the mud, which affect the cost of drilling mud in the relevant drilling well (Table 17).

Table 17. Drilling fluid's central cost drivers for the entire well

Cost drivers	Total Price (€)
Product	45,372.25
Equipment	9,525.00
Waste management	3,150.00
Personnel	17,250.00
Transportation	1,500.00
TOTAL	**76,797.25**

Cost per feet drilled and cost per barrel for mud systems are the main parameters for optimizing drilling operation. Figure 6 and Figure 7 demonstrated the cost per feet and cost per barrel for Gypsum-Polymer mud and KCl/Gypsum/Polymer mud, respectively. The cost per feet and cost per barrel of mud changed depending upon the mud systems formulation and both the cost per feet and cost per barrel of KCl/Gypsum/Polymer mud was higher than Gypsum-Polymer mud. As can be seen from the figures, while cost per foot drilled of gypsum/polymer is € 10.605, and it was calculated as € 14.282 for KCl/Gypsum/Polymer mud. On the other hand, the cost per barrel of gypsum/polymer and KCl/Gypsum/Polymer mud were € 14.012, € 27.121, respectively. It should be noted that only drilling mud cost drivers were taken into account in the calculation of cost per barrel of drilling mud and cost per feet, and other factors such as drilling bit selection, rate of penetration, weight on bit and torque were not included in the calculation.

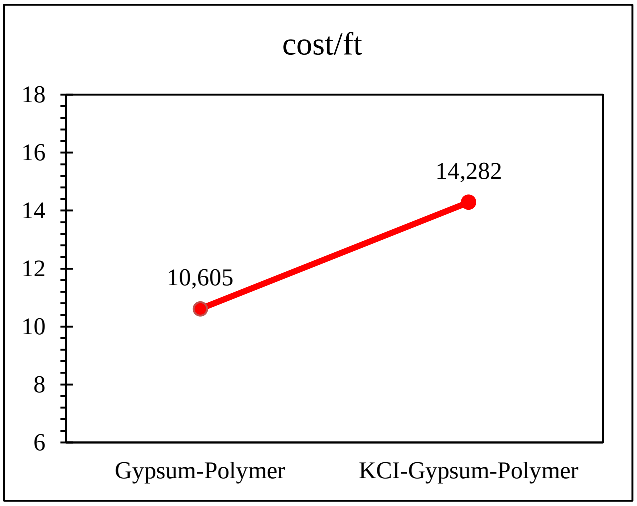

Figure 6. Cost/ft for each mud

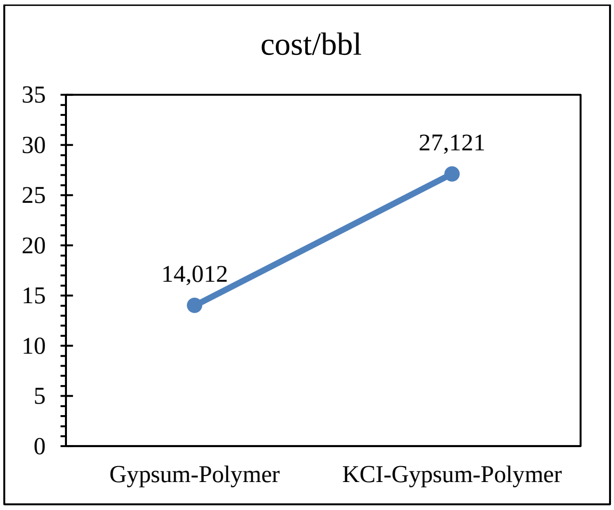

Figure 7. Cost/bbl for each mud

4. CONCLUSION

A comprehensive analysis in term of cost and benefit for 2 type of drill fluids (gypsum/polymer and KCl/gypsum/polymer) was provided, which were used to drill a well located in north of Hungary. The following conclusions were drawn from the study:

- The results of the analysis showed that the additives are the main cost dominator (59%) followed by transportation, waste management, and personnel (23%), finally mud cleaning system (12%).
- € 45372.25 was the total cost of mud additives used in the studied drilling sections, where 24% of the overall cost was disbursed for lubricant and 30% for fluid loss controllers.
- The highest mud cost was observed in the section where the 8 1/2 in bit was used. The ratio of the cost of drilling fluid used during the penetration of this well diameter to the total cost of drilling fluid was determined as 58%.
- The result of the study shows that 3,937 bbl of drilling mud was used altogether and the total cost was calculated as € 76,797.25. On average, the cost per barrel and cost per foot of drilling fluid used during the entire drilling were calculated as 12.319 €/ft and 19.50 €/bbl, respectively.

Overall, results obtained based on the study will serve as a guideline for selecting and analysing drilling mud systems in terms of cost and will benefit to evaluate the economics of the novel drilling fluid systems put forward by investigators and assist to determine whether the mud systems are economically viable or not. The results will also benefit the selection of products for formulation of drilling mud and analyse/predict prices for drilling mud systems and can assist drilling enterprises better understand the market, the industry cost calculation procedures and allow them to understand their peers.

Declaration of Ethical Standards

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

Contribution of the Authors

Emine Yalman: Conceptualization, Methodology, Writing – original draft, Reviewing and Editing.
Gabriella Federer Kovacsne: Supervision, Conceptualization, Validation, Methodology.
Tolga Depci: Supervision, Conceptualization, Validation, Methodology.

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