Proper Grain Diameter Composition Can Transform Useless Domestic Sand into Micro - Proppant for Unconventional Reservoirs in Poland

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Abstract

The paper investigates the possible use of a low strength domestic sand (D) (up to today useless – not considered as proppant source) of small particle sizes, instead to that of high strength imported commercial sand (C), as a prospective micro-proppant for low permeability reservoirs in Poland. There is need to develop national unconventional gas resources like tight gas, shale gas and coalbed methane. An important energy source of value and readily available in Poland is coal. The basins of this resource are large and bears low permeability coalbed methane reservoirs which needs to be developed to contribute to the energy security, economy and environmental needs of the country. These reservoirs need technological assistance such as hydraulic fracturing which makes use of proppants for development. Most of the commonly used proppants over the years for fracturing have been large grain size commercial proppants of high strength material content bought abroad. Investigated finer proppants are known to have the ability to penetrate narrow fracture networks to ensure effective high reservoir volume and conductivity for production.

Results from presented laboratory research shows the D - proppant, which is cheaper and readily available, has the 3K class with low settling rates as a potential micro-proppant for effective transportation, enhancement of conductivity and production rate in the narrow fractures of low permeability reservoirs. Future using of domestic proppant will decrease stimulation cost and will have positive impact on the environment due to omitting long distance transportation from abroad.

Keywords: Proppant; Hydraulic Fracturing; Unconventional Reservoir; Sand; Settling Rate; Crush Rate; Mesh Size; Grain Diameter; Proppant composition; Micro proppant

1. Introduction

Low permeability reservoirs are reservoirs with natural layers and fractures known to exhibit low production of hydrocarbons unless assisted with stimulation technology. Production of the world's hydrocarbon today is much dependent on unconventional reservoirs, than the conventional ones comparing to the XX century. Examples of these are shale, coalbed methane and tight gas. Coal is amongst the group of mineral raw materials of high value in Poland. It is known as a contributor to the economy and energy security of the country. Coal accounts for quite a percentage of the energy demand of the country and over 75% of its primary energy production [1]. The upper and lower Silesian basins in the country are known to have a good amount of coalbed methane. The future forecast of the development of these low permeable reservoirs in Poland is known to be contributing to the energy economy through reduction in gas imports and prices as well as reducing emission of pollutants. On the other hand conventional reservoirs possess high percentage and longer period supply of hydrocarbons. Unconventional plays are much more challenging from technological point of view. They also usually have a complex fracture geometry, for this reason it is important to take into account the interaction of the natural fractures with the hydraulic fractures. The existence of natural fractures can affect the fracturing process and conductivity [2]. Apart from main wide fractures also micro fractures are created during stimulation process. 20/40 mesh proppant (mainly used in Poland) is not able to migrate into such small fractures. For this reason finer proppant is needed in hydraulic fracturing where micro fractures are generated to be propped open to increase production [3].

To create and prop fractures, proppant together with fracturing fluid is pumped down the wellbore. The fluid pumped before the main injection of the fracturing fluid is called the pad. The pad fluid is known to compose of various soluble additives but no solid phase, whereas the fracturing fluid contains proppant. Fracturing fluid is basically composed of about 90% water, 9.5 % proppant and 0.5 % of additives. It should also be noted, fracturing job profitability depends on rock environment and reservoir properties (not controllable) and many technological parameters that can be controlled by engineers to achieve maximum efficiency [4]. For example viscosity has important role in fracture propagation and increase in this parameter can cause an increase in fracturing pressure and cost, on the other hand which can decrease conductivity of fracture [5]. The existence of low width secondary/micro fractures in unconventional reservoirs mean the need to search and employ the use of finer proppants with smaller mesh range sizes. Due to the width of these micro fractures, the pumping of a fracturing fluid with proppants that cannot penetrate in these smaller zones/fractures will tend to close them up resulting in a waste of the stimulated reservoir volume. To prevent this and ensure penetration as well as conductivity in these fractures, finer proppants must be used. Proppants are materials such as sand, resin-coated sands and ceramic used to hold fractures open to enhance conductivity and increase production of hydrocarbons [6]. Although it is known to have a small percentage of composition of the fracturing fluid, it plays an important role in the treatment. Proppants with characteristics such as high strength and fair price are readily used in fracturing of unconventional reservoirs. Low bulk density proppants with reasonable price are also desirable due to better transportation properties comparing to higher bulk density material with the same properties and price. Lower bulk density proppant has also lower settling rate and can reach longer distance suspended in hydraulic fracturing fluid. Basically, in a stimulation treatment consideration of proppant different grains proportion, size, crush rate, stress conditions, production and workover pressure cycles, permeability and conductivity are key parameters for engineering hydraulic fracturing process design [7, 8, 9].

Sand continues to remain one of the widely and commonly used proppants since late 40's when hydraulic fracturing started [10]. It has always known to be used in treating shallow wells, due to lower in-situ stresses, comparing to the deep ones. Its common usage in the industry followed by resin coated and ceramic proppant is attributed to its high percentage of total volume [11]. 100 mesh proppants are of uniform size hence can enhance fracture conductivity [12]. Its usage is common in the industry. As a result of the continuous advancement of technological processes in relation to the effective stimulation and accessibility to micro fractures for high production, proppants which are finer than the 100 mesh proppants were incorporated. As a next step in technology advancement nano proppants are introduced in research and practice. Micro proppants are proppants which have fine particle sizes not larger than 100 mesh or 200 mesh. These proppants are also injected at the initial stage of treatment, they hold open fractures that cannot be entered by larger size proppants [13]. They are important proppants which prevent the closing of micro fractures and also help decrease pressure used in treatment to ensure enhancement of fracturing [14]. Nano proppants are very fine proppants known to be of particle size in a range of 100nm -1μm. In their composition spherical particles are dominating. These proppants are migrating much better then micro proppants and keep very narrow fractures open after the stimulation process. The introduction of smaller grains proppants before larger ones helps to increase total cumulative fracture length. They are also known to possess the ability needed to withstand stresses which they are subjected; they can resist higher loads with reference to crush resistance [11, 15].

All these fine proppants, with high mesh size(micro and nano proppants), have the ability to limit fluid loss to fractures. They are therefore considered as a prior preventive proppant and are also used after the injecting of the pad [16, 17]. They also show better settling velocity rate as well as transport ability in the fractures and hold open them to contribute to conductivity enhancement. Additionally, an enhancement in viscosity of water based fracturing fluids with such proppant and stability of foam fluids for hydraulic fracturing was observed [18]. Study by Masłowski at al. [19] indicates that the higher diameter proppants, mainly used for unconventional formations, may easy show embedment phenomenon and fracture damage as a result. Research on fine proppants proved that usage of such material is fruitful and they are known to increase production in wells [20].

2. Methods

Commercial sand proppant (C) like 20/40 mesh, which is of high strength material content is mostly used in Poland by industry in hydraulic fracturing jobs. These high strength material content materials are provided from abroad. For this reason, the transportation and cost of these proppants are high so researchers and local industry are looking for national resources of proppant [21]. Conventional proppants also yield low reservoir volume due to their inability to hold open smaller widths fractures. 20/40 proppants are transported on shorter distances in fractures comparing to micro and nano proppants which have the ability to penetrate and to hold open secondary fractures yielding a high reservoir volume and conductivity. This paper investigates possibility of using a low strength material content domestic sand (D) (up to today useless – not considered as proppant source), which is a cheap local material readily available in Poland to that of a commercial sand (C) of high strength material content as a potential proppant for unconventional reservoirs.

The most important part of this research is to investigate influence of grain composition on the proppant strength (confirmed in petroleum industry by crush test) and proppant transportation (confirmed in petroleum industry by settling velocity). After many attempts three mass proportions were assumed for both types of sand as shown in Table 1.

Table 1a. Proppant formulation for D - 20/40 and C - 20/40 mesh.

Proppant label	Proppant mass proportions	
	30 mesh	40 mesh
10	90 %	10 %
50	50 %	50 %
100	0 %	100 %

Laboratory measurements include: sieve analysis, bulk density, crush test and settling rate. To avoid influence of moisture on the measured quantities each sample was dried in the oven for 24 hours at 105°C temperature. It was found commercial proppant has different grain composition depending on sampling. To avoid influence of different grain size composition on proppant performance commercial proppant was also separated into exactly same grain sizes and made in the same mass proportions as domestic sand.

Dried sand was separated out in given mesh sizes using sieve stack. Sieve openings used in experiments are shown in the Table 1b.

Table 1b. Mesh sizes and sieve opening

Sieve Size (mesh)	Sieve opening (μm)
20	841
30	595
40	420
100	149

140	105
200	74

Then assumed proportions according to Table 1a were mixed to get proppants samples. Low strength material content domestic sand and high strength material content imported commercial sand have been tested according to the API RP 19C and PN-EN ISO 13503-2:2010, 2010 standards.

3. Results and Discussion

In the first attempt C - 20/40 mesh and new D - 20/40 mesh proppants properties were compered.

Bulk density which is defined as the dry weight of samples per unit volume was determined in the first instance. This parameter is known to relate proppant strength and porosity [22]. It was observed that bulk density of investigated proppants tends to be decreasing as a greater proportion of the fine grain particles were used in formulation (Table 2 and 3).

Table 2. Proppant bulk density for D - 20/40 mesh.

Proppant label	Bulk density (kg/m^3)
10	1650
50	1620
100	1600

Table 3. Proppant bulk density for C - 20/40 mesh.

Proppant label	Bulk density (kg/m^3)
10	1730
50	1720
100	1710

In the nonuniform grain size composition the smaller grains fill gaps between larger ones and for this reason porosity is decreasing. In the uniform proppant size composition porosity is higher and results in lower bulk density. Higher bulk density for the same mesh size proppants is not desired in the petroleum industry because of worse transportation properties. The D proppants have advantage due to lower bulk density according to Tables 2 and 3.

The sand proppants were later subjected to crushing at maximum stress of 27.58 MPa (4000 psi) and their strength were determined under K - class. Results are presented in the Table 4.

Table 4. Crush rate of 20/40 mesh size proppants at 27.58 MPa (4000 psi).

Proppant label	Crush rate (%)	
	D - 20/40 mesh	C - 20/40 mesh
10	19.25	8.98
50	24.3	10.2
100	27.5	10.87

With reference to the crush rate of proppants in the Table 4, D - 20/40 proppant cannot be applied in the stress conditions of 27.58 MPa (4000 psi) because crush rate is higher than 10%. For commercial one only C - 20/40 mesh size with label 10 is fulfilling requirements of 4K - class. Authors decided to check if tested domestic sand can be used for micro – proppant production. Table 5 shows three formulations for new measurements using fine grain domestic sand.

Table 5. Proppant formulation for D - 100/200 mesh.

Proppant label	Proppant mass proportions	
	140 mesh	200 mesh
10	90 %	10 %
50	50 %	50 %
100	0 %	100 %

Accordingly to previous step bulk density was checked for new 100/200 mesh domestic proppants. Results are presented in the Table 6.

Table 6. Proppant bulk density for D - 100/200 mesh.

Proppant label	Bulk density (kg/m^3)
10	1430
50	1410
100	1400

As expected with increasing grains diameter homogeneity (increasing label values), domestic sand bulk density decreases. It is worth to notice that new micro – proppants are showing lower bulk densities comparing to commercial and domestic 20/40 mesh proppants as in Tables 2 and 3 accordingly. In terms of future commercialization it could be strong selling point. To check applicability for stress conditions crush test was performed. Table 7 presents crush rate values of 100/200 mesh size D proppant at 27.58 MPa (4000 psi).

Table 7. Crush rate of 100/200 mesh size D proppant at 27.58 MPa (4000 psi).

Proppant label	Crush rate (%)
10	5.4
50	6.6
100	13.9

It was found that nonuniform (labels 10 and 50 in the Table 7) D – 100/200 proppants can easy fit to 4 K – class, crush rate is much lower than 10%. Grains diameter homogeneity is not merit because 100% of 200 mesh grains in proppant formulation (label 100 in the Table 7) shows lowest value of crush rate and is considerably higher (on 3.9%) than 10%. Question is how investigated proppants pass lower stress test. All formulations were subjected crush test under 20.68 MPa (3000 psi). Measurements results are shown in the Table 8.

Table 8. Crush rate at 20.68 MPa (3000 psi).

Proppant label	Crush rate (%)		
	D - 20/40 mesh	D - 100/200 mesh	C - 20/40 mesh
10	8.75	3.12	6.38
50	15.38	4.88	7.03
100	15.52	9.28	7.56

Research shows that commercial sand can easy be classified under 3K – class, all crush rates of C – 20/40 mesh are much lower than 10%. It was observed that D - 100/200 mesh proppants (all labels) passed the test at 20.68 MPa (3000 psi) and qualify to be classified under 3K as shown in Table 8. Although mixing larger grains with fine particles like D - 20/40 mesh, label 10 gives 3K proppant. Such solution is more expensive (due to additional procedure in the production cycle) but allows using even pretty large grains lower quality sand for 3K-class applications.

The settling rate of proppants is also known to have influence on its placement in the fracture. Although, proppants of larger size particles are known to yield higher permeability, finer proppants mostly have the ability for propping narrow fractures due to low settling rate and this enhances production. Laboratory research investigated also this property of proppants. Figure 1 shows comparison of settling velocity values in water for all the tested sands, both commercial and domestic one.

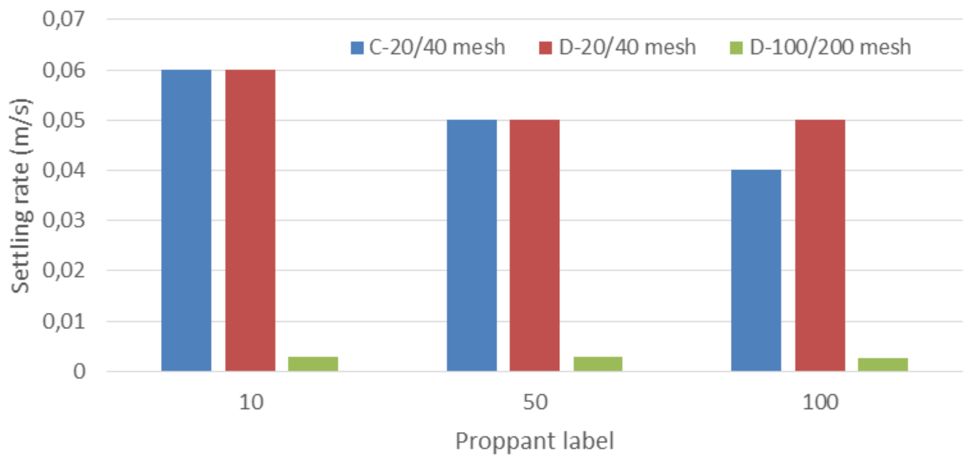

Fig 1. Settling rate of 20/40 and 100/200 mesh proppants in water.

At Figure 1 blue color is for commercial proppant 20/40 mesh, red for domestic proppant 20/40 mesh and green for domestic proppant 100/200 mesh. It was observed that the proppants with greater amount of larger grains in mixture composition (label 10) shows highest values of settling rate. Usually engineers in industry prefer lower bulk density proppants comparing to other with the same rest of the parameters. But small difference in bulk density (Tab. 2, 3 and 6) appears to have also small influence on settling velocity (Fig. 1) so not necessary it is worth to pay more in case when rest proppant properties are the same. Definitely there is large difference in transportation properties between 20/40 mesh and 100/200 mesh proppants. Settling rate of 100/200 mesh D - proppant are about 15 - 20 times lower than that of 20/40 mesh proppant as it is shown in Fig 1. It means, the finer particles sizes enable better transportation in hydraulic fracturing fluid and penetration into micro and narrow fractures to enhance conductivity within these fractures to help increase production rate in unconventional reservoirs.

Conclusions

1- The findings indicate that the domestic investigated material may be applied as potential micro-proppant that could be used for hydraulic fracturing in unconventional formations in Poland.

2- Application of domestic sand as a proppant can lead to decrease stimulation cost and decrease impact on environment by substantial catting of transportation distance.

3- The decrease in bulk density as proportion of finer grains increases mean a higher porosity of proppant pack to improve flow conductivity in narrow fractures.

4- The very low rate of settling of finer particles in the case of 100/200 mesh proppants shows its potential to penetrate and prop narrow fractures for production improvement as compared to larger particle sizes proppant.

5- Proper grains size composition is the useful method to improve proppant properties using the same row material.

6- Small difference in bulk density has also minor influence on the settling rate but it could be strong selling point for proppant producing company.

ACKNOWLEDGEMENTS

The project was supported by the AGH subsidy 16.16.190.779.

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