RESERVOIR STIMULATION

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- Coal reservoir stimulation is a process of enhancing coalbed gas production by cleaning up the borehole of damage during drilling and completion using different fracture treatments.
- Stimulation dilates, opens, and extends the width, length, and connectivity of the natural fracture systems (e.g. butt and face cleats and mega fractures) of the coal reservoir.
- Successful fracture stimulation treatments in coal reservoirs commonly include plain water, gel, foam fluids and sand proppant. Each of these treatments has its own advantages and disadvantages.

Examples

- Plain water is environmentally preferable and tends not to damage the skin or wall of fractures.
- The chemical additives tend to adhere along the surfaces of the fractures as cakes as well as have the tendency to plug the fractures.

What is Hydraulic Fracturing?

- Hydraulic fracturing is the process of transmitting pressure by fluid or gas to create cracks or to open existing cracks in hydrocarbon bearing rocks underground.

- The purpose of hydraulic fracturing is to breakdown the coal and create fractures that allow gas to flow through the coal matrix to the fractures and then to the wellbore, a process known as **stimulation**.

- This is done through injecting a high-pressure fluid (water, gas, foam) down the well bore, through the perforation and into the coal seam. In order to keep these fractures open for gas to flow to the well bore, a proppant of coarse sand is injected with the high pressure fluid. Finally the water is removed from the formation to decrease the pressure of the bed and to allow for the methane to be desorbed and be produced through the well.
- Hydraulic fracturing is the application of fluids consisting of plain water or water-based additives, which are pumped into the coal reservoir at high pressure. The fluid pressure normally exceeds the tensile strength of the coal reservoir such that the fluids open, lengthen, and enlarge fractures and cleats many of which extend tens of meters from the well, improving their connectivity.

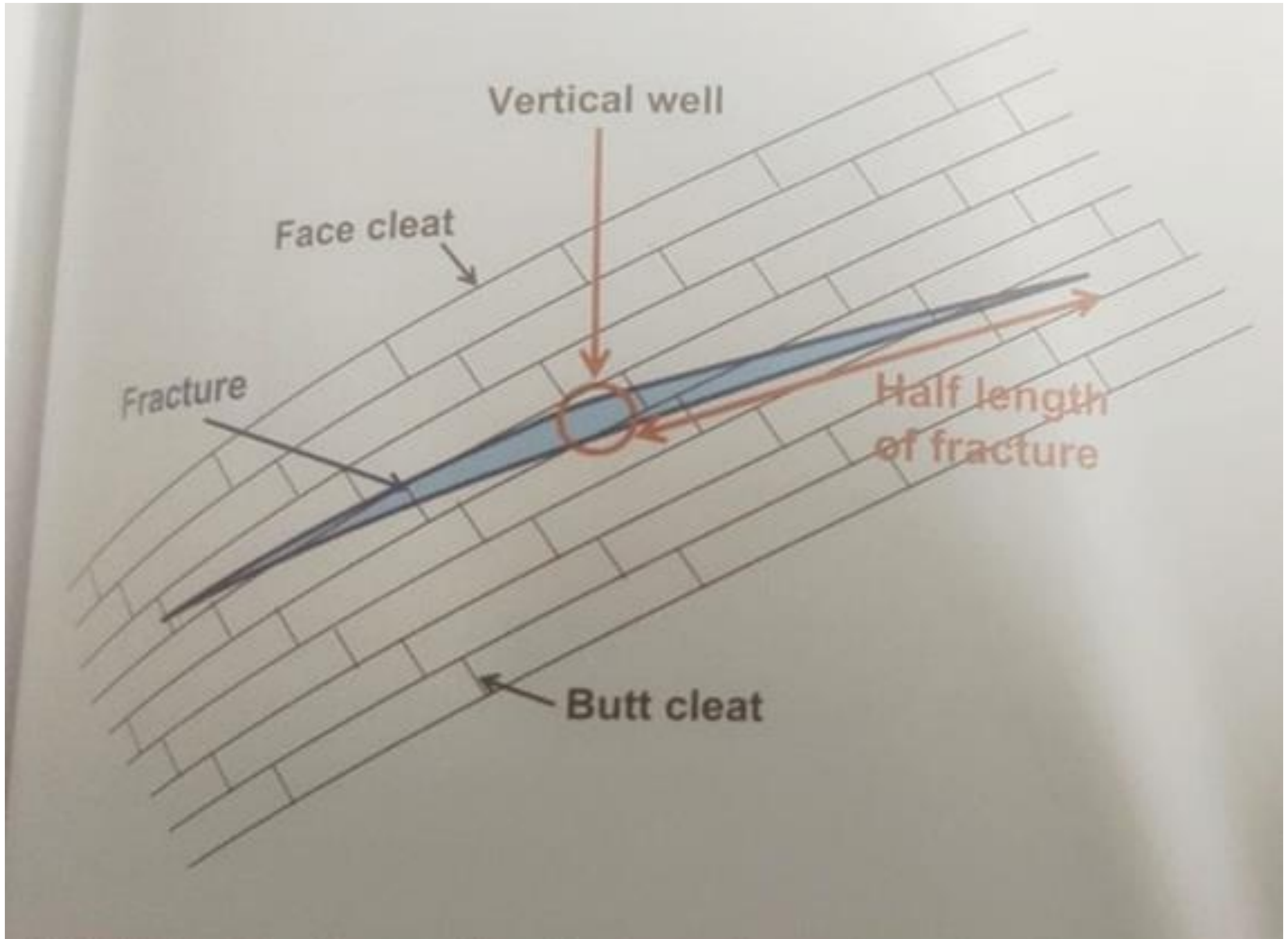

FIGURE 7.17 Generalized plan view showing location of a vertical well in a coal bed with orthogonal face and butt cleat orientations. The fracture created by stimulation shows a half-length from the well to the endpoint connecting face and butt cleats for gas to flow to the wellbore.

The opened fractures then permit the fluids to penetrate the network of fractures and cleats allowing avenues of water and gas to flow (e.g. Darcy flow) during dewatering and degasification

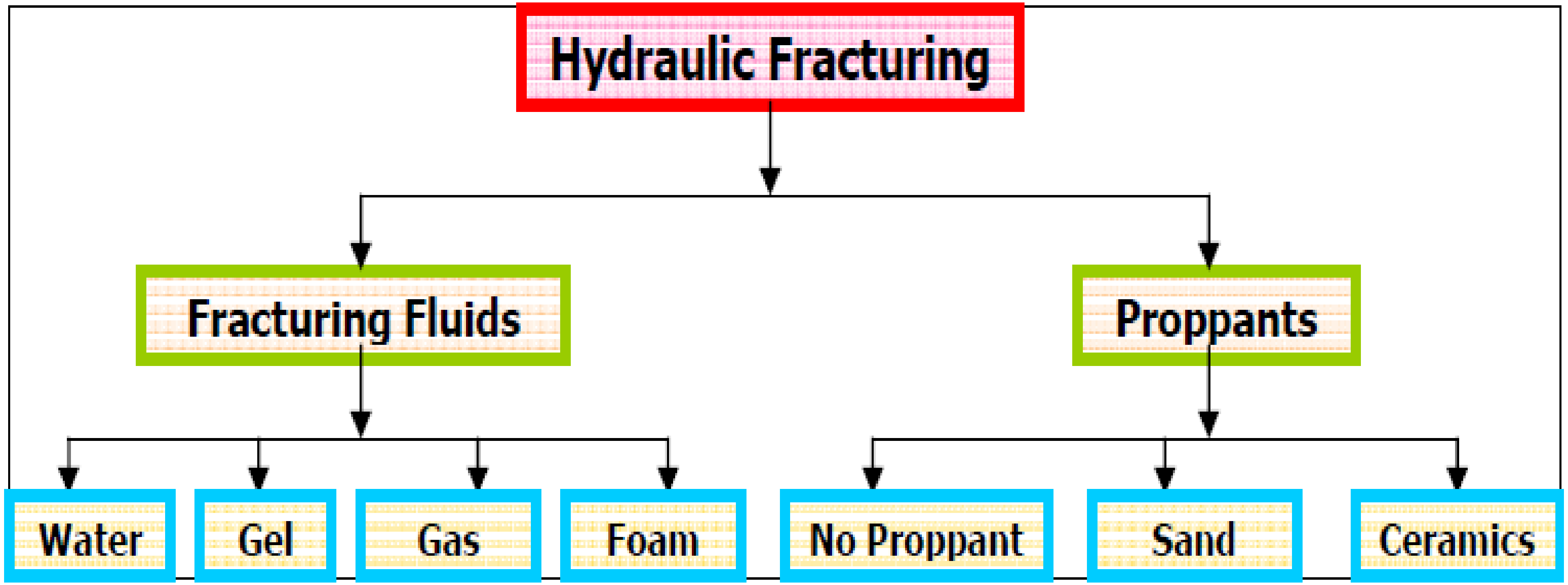

Figure : Hydraulic fracture stimulation fluids and proppants used for CBM reservoirs

TABLE 7.3 Composition of Hydraulic Fracturing Fluids for Stimulation Treatment of Coalbed Gas Wells

Product	Chemical Composition	Hazard/Toxicology	Ecological
Linear gel			
Delivery system	30–60% by wt. guar gum derivative	Harmful when swallowed; combustible.	Slowly biodegradable
	60–100% by wt. diesel	Chronic effect/carcinogenicity.	Not determined
Polymer	<2% by wt. fumaric acid; adipic acid	Flammable vapors	Partly biodegradable
Polymer slurry	30–60% by wt. diesel oil #2	Causes irritation when swallowed; flammable. Carcinogenicity	
Water gel	60–100% by wt. guar gum	None	Biodegradable
	5–10% by wt. water	Mildly eye irritant	
	0.5–1.5% by wt. fumaric acid	Chronic effect/carcinogenicity	
Cross-linker	10–30% by wt. boric acid; ethylene glycol; monoethanolamine; sodium tetraborate decahydrate	Harmful when swallowed; combustible Mildly irritant to eyes, skin;	Not determined Partly biodegradable Low fish toxicity
Foaming agent	10–30% by wt. isopropanol; salt of alkylamines; ethanol; 2–butoxyethanol; water	Harmful if swallowed or absorbed in skin; highly flammable	Not determined Harmful to aquatic organisms
	1–5% by wt. diethanolamine	Chronic effect/carcinogenicity	
	25–55% by wt. ester salt	Eye, skin, and respiratory irritation	
	0.1–1% by wt. polyglycol ether		

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Acid treatment	30–60% by wt. hydrochloric acid 85% by wt. formic acid	Harmful if swallowed; Eye, skin, and respiratory burns Chronic effect/carcinogenicity	Not determined
Breaker fluid	60–100% by wt. diammonium peroxidisufhate	Harmful if swallowed; Eye, skin, and respiratory burns. Tissue damage	Not determined
Microbiocide/biocide	60–100% by wt. 2-bromo-2-nitrol, 3-propanedol; 2-dibromo-3-nitrilopropionamide 1–5% by wt. 2-Bromo-3-nitrilopropionamide	Harmful if swallowed Eye and skin irritation; causes severe burns and allergic reaction on repeated skin exposure. Discomfort to mouth, throat, and stomach Chronic effects/carcinogenicity	Not determined
Acid corrosion	30–60% by wt. methanol; pyridinium, 1-(phenylmethyl)-, ethylmethyl derivatives, chlorides 5–10% by wt. propargyl alcohol, propan-2-ol 15% by wt. thiourea 1–5% by wt. Poly(oxy-1, 2-ethanediyl)-nonylphenyl-hydroxy 10–30% water	Fatal if swallowed; causes eye and skin irritation/burns, headache, dizziness, blindness, central nervous system effects, burns in respiratory tract; injury to lungs, throat, and mucous membrane; and tissue damage Chronic effects/carcinogenicity	Partly biodegradable Toxic to aquatic organisms

Plain water and potassium chloride water

- Plain water hydraulic fracturing is pumping coproduced or formation water and/or treated water to stimulate the coal reservoir. This treatment is preferred for highly fractured coal reservoirs where water pressure can be applied and still achieve enlarging and lengthening fracture, and cleat systems.
- The advantage of using plain water treatment is that it is an economical or low-cost application and is an environmentally friendly process of reservoir stimulation.
- Proppants may or may not be used with plain water treatment. The plain water transporting capacity or density is about 100-200 kg/m3 due to low viscosity, which is adequate but not as efficient as the gelled fluids. This carrying inefficiency may result in lower rate of groundwater and coalbed gas flow and thus gas production.

- A modification of plain water fracturing is water with potassium chloride with gelled fluids, polymers, and surfactants.
- Plain water and water-based fluids normally must be pumped at high rates or velocities and optimal pressure to be most effective. This process, in turn, results in friction damage to the coal face around the borehole and fracture and cleat surfaces found beyond the borehole. Thus, friction reducers (e.g. latex polymers and copolymers of acrylamides) are added to the water-based fracturing fluids to mitigate the friction damage.

Gelled fluids

- The limitations of plain water treatment led to the introduction of water-based gelled fluids for more viscosity and longer conveyance of proppants.
- The use of water gelates, which are thickeners, is based on the permeability, porosity, pressure, temperature, and thickness of the coal reservoirs.
- In order to increase the viscosity of plain water, the service industries introduced gelled fluids composed of linear and cross-linked fluids.

Linear fluid

- A linear fluid is composed of gum and guar derivatives (e.g. hydroxypropyl guar and carboxymethyl hydroxypropyl guar) and cellulose derivatives (e.g. carboxymethyl guar and hydroxyethylcellulose).
- The chemical properties of guar gum, which are relevant for use in hydraulic fracturing fluids, are the capacity to (1) suspend solids, (2) bind by hydrogen bond with water, (3) control viscosity of aqueous solutions, and (4) form hard films.

- These properties of guar gum are harnessed to formulate a gel to increase fluid viscosity for efficient conveyance of sand proppants and turbulent flow.

Cross-linked fluid

- Cross-linked fluid or gel is composed of metal-ion-cross-linked guar made possible by metal ions (e.g., aluminum, chromium, titanium), later complemented by low-residue cleaner such as cross-linked hydroxypropyl guar.
- Cross-linked gels are combined with linear gel fluid in order to permit more effective conveyance of the proppants and thus, increased coalbed gas production.

Foam gels and Gas

- Hydraulic fracturing with foam, which is formed by trapped gas, is used to carry proppants into the fracture and cleat systems in coal reservoirs.
- Foams are much like beer bubbles from freshly opened bottle charged with gas as it pours out. The fracture fluids of foam utilize nitrogen and carbon dioxide as basic gas components.
- The combined foam and gelled fluids are valuable in coal reservoirs with low permeability and hydrostatic pressure.

- A major advantage of using foam gels is less damage to the fracture permeability of the coal reservoir. However, foam mixtures may leak from the wellbore, which necessitates the use of fluid-loss additives such as fine-grained materials (e.g. 100 mesh sand and resin, silica flour, clay, and plaster materials). The disadvantage of this is that the additives have a tendency to plug the fractures and cleats of the coal reservoir.
- Another disadvantage of the foam and gas mixture is carbon dioxide migrating into the pore systems (e.g. micropores, mesopores, and macropores), which in turn is adsorbed onto the pore surfaces, leading to plugging and swelling of the coal matrix and constricting passageways, thus ruining the permeability.

Acids

- Acid stimulation or acidizing in association with hydraulic fracturing is a process of dissolving minerals (e.g. inorganic matter) in the coal reservoir.
- The acidizing process is applied only when there is pervasive mineralization of the fracture and cleat system. When applied, the acid dissolves the inorganic minerals that plug the fractures and cleats, resulting in opening and interconnecting passageways to flow water and gas through the reservoir.
- Acidic stimulation fluids include hydrochloric, acetic, and formic acids or combinations of these acids.
- The acids are typically pumped into the reservoir at low concentration typically resulting from dilution with water-and gas-based fluids.

- Gelled and water-methanol fluids are combined with acidic fluids in order to increase the distance of transport to reach additional mineralized fractures and cleats.

Proppants

- A significant solid additive to hydraulic fracturing fluids is proppants, which are emplaced in the fracture and cleat systems for support. The main objective when fracturing a coal seam is to interconnect the cleat system with the wellbore.

- The proppants are in the form of silica sand, resin-coated sand, or ceramic sand.
- The properties of proppants in a pack are 20-40 mesh, 82 degree Celsius, and 27.6 MPa.

- The size of the proppants depends on the width of the fractures and cleats. Larger proppants allow for wider fractures for better Darcian gas and water flow and better fracture fluid flow back. Thus, the permeability of the coal reservoir secondarily depends on the size as well as the strength, roundness, and purity of the proppants.

- One disadvantage of using proppants combined with hydraulic fracturing fluids of high viscosity is the production of fine-grained materials in the fracture and cleat systems and around the borehole.