

# ***FLUIDIZED BED***

**Created by Teachers  
Engineers, and Scientists**



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## ***BACKGROUND /INFORMATION FOR FLUIDIZED BEDS***

*Fluidized-bed combustion provides a highly efficient means of generating low-cost electricity from coal and other fuels with minimal impact on the environment. This promising new technology will enable our Nation to continue to rely on coal to help meet our growing energy needs in the future, and at the same time, help solve environmental problems. It is also expected to capture a share of the emerging global market for cleaner power generation technologies.*

**Power Magazine** has called the development of fluidized-bed coal combustors “the commercial success story of the last decade in the power generation business.” **U.S. Department of Energy - Federal Energy Technology Center Fluidized-Bed Combustion [April 1998]**

A major goal of the United States Department of Energy’s Fluidized Bed Combustion System is to reduce sulfur emissions by 99%, oxides of nitrogen by 95%, and CO<sub>2</sub> by 25%. These advanced units should operate in excess of 50% efficiency and cost approximately 25% less to build than today’s conventional non-fluidized bed combustion units.

## **Fluidized Bed Lesson Plan**

Grades: 6-12

Duration: **5** (40 minute) sessions

### **OBJECTIVES:**

1. The students will describe the purpose and components of a Fluidized Bed.
2. The student will demonstrate knowledge of scientific vocabulary used in Fluidized Bed Construction.
3. The students will attain an appreciation for the benefits of a Fluidized Bed as it pertains to their environment.
4. The student will construct a small- scale functional Fluidized Bed from common household materials.
5. The student will gain an appreciation for the work done by scientists to solve energy and environmental problems.

## **Procedures/Activities:**

Fluidized Bed Combustion Technology is one of the technologies being developed by the Department of Energy at its Federal Energy Technology Center. It is a technology which can burn coal without the need for expensive pollution control technology. During fluidized bed combustion, pollutants are captured very soon after they are generated and are never released into the environment. The technology has proven to be a potential means of lowering the cost of electricity production while maintaining a high standard of living. Because of the increased operating efficiency of a fluidized bed combustion system, greenhouse gases will be reduced as well as the United States' dependence on imported fuels. We can reduce the use of our valuable limited resources in the production of electricity.

In addition to burning coal, fluidized bed combustion technology can be used to burn many waste materials like municipal trash, and hospital medical waste.

There are two types of fluidized combustion systems: atmospheric and pressurized. Atmospheric systems, as the name implies, allow the combustion to occur at atmospheric pressure while in pressurized ones, the combustion occurs at increased pressure. Operation at elevated pressures result in a high pressure gas stream that is used to drive a gas turbine for creating electricity.

### **1. Present background information to the students.**

- Propose a problem of the Earth's Pollution.
- Global Warming and how it effects us. El Nino and/or La Nina.  
(Internet weather channel live report)
- High sulfur coal as a pollutant. Ex. Sulfur streams are red.
- Introduce research via Internet web sites.

### **2. Introduce and discuss Fluidized Bed vocabulary.**

- Prior knowledge of common words vs scientific terms.
- Discuss scientific definition of the common words.

### **3. Discuss basic physical principles involved in the Fluidized Bed process.**

- Scientific laws and principles covered.

### **4. Show parts of Fluidized Bed and discuss function of each.**

- Use picture of an actual Fluidized Bed.
- Explore how it works and the purpose served.

### **5. Construct and operate a small-scale Fluidized Bed that closely simulates a large-scale Fluidized Bed.**

- Use household supplies for the building of a Fluidized Bed (material list included).

**Brainstorm how the Fluidized Bed will operate using the scientific method.**

- Propose a hypothesis with predictions.
- Conduct experiment.
- Was the hypothesis met?
- Discuss results and draw conclusions of the activity.

**6. Explore scientific and other career opportunities involved in solving energy and environmental problems.**

Chemist

Physicist

Engineer

Technician

Biologist

Computer Scientist

Miner

Metal Workers

## **ENRICHMENT ACTIVITIES [Areas of Research]**

**Pressurized Fluidized Bed Combustors (PFBC)** are only one of several advanced approaches for substantially improving the efficiency of coal-fired power systems, while significantly reducing environmental emissions. The PFBC system uses sorbent such as limestone or dolomite to capture sulfur released by the combustion of coal. Jets of air suspend the mixture of sorbent and burning coal during combustion, converting the mixture into a suspension of red-hot particles that flow like a fluid. Elevated pressures and temperatures produce a high-pressure gas stream that can drive a gas turbine, and steam generated from the heat in the fluidized bed is sent to a steam turbine, creating a highly efficient combined cycle system.

**Biological Filter System** - The most efficient and dependable biological filter is the fluidized bed filter. The principles of this filter are very attractive to commercial applications because of the dramatic increase in surface area and reduced real estate requirement. Providing that the design of the fluidized bed is sound, this style of biological filter is by far the most efficient. Competing styles such as the rotating barrel contractors and packed-column towers (wet dry filters) are not as attractive as the fluid bed filter. It tends to accumulate particle waste or contains too many moving parts. The fluidized bed filter with its tremendous surface area is about as close to automatic as is developed.

**Fluid Bed Catalytic Cracking** has been used since the 1940's to produce high octane gasoline. The gasoline produced by this process has allowed the development of the modern automobile engine and the wide spread use of cars around the world.

The simple distillation of crude oil does not produce sufficient amounts of gasoline to meet world wide demand. Cracking higher molecular weight hydrocarbons into lower weight ones allows the production of more gasoline. The catalytic breakdown of hydrocarbons into lower molecular materials is dominated by two features: the reactions require energy to occur (are endothermic) and carbon is left behind on nearby solid surfaces.

### **Fluidized Bed Materials List:**

<b>Quantity</b>	<b>Description</b>
1	cardboard box (about 30 cm on each side)
2	2 liter plastic soda bottles
1	hair dryer with cold air setting
1,000 cm <sup>2</sup>	flexible plastic window screen (1 ft <sup>2</sup> )
2 cups	puffed rice cereal
1 roll	duct tape
1	utility knife
1	30 cm ruler (12 inch)

### **Optional Materials:**

3 feet	1/4" Diameter clear plastic tubing for measuring the plenum air pressure
2 cups	Rice Krispies cereal
2 cups	Grape Nuts cereal

## Project Instructions:

1. Cut off two 2-liter bottles eight cm. (three inches) from the top and eight cm. from the bottom. You will have a straight section of plastic bottle with a uniform shape. Fit the two pieces together.



2. Cut a round hole into the top of the box so that one of the straight sections made in STEP 1 will fit snugly into the hole. (Keep the piece of cardboard cut out.)



3. Cut three square pieces of window screen about three cm on each side larger than the hole made in STEP 2. Stack these three pieces on top of each other and tape the sides together. Make sure the tape does not cover more than 1 cm of the screen's edge. Cover on the inside the hole made in STEP 2 with the screens and tape them into place. Fit the center piece from the 2 liter bottle into the hole and tape it securely in place so that air can not leak around the piece.



4. Cut a hole on the side of the box to insert the discharge end of the hair dryer. The end should fit snugly into the (plenum) box.
5. Cut a six cm. (two-inch) vent hole on the opposite side of the box. This vent will be used to adjust the amount of air flow into the fluid bed. Cover the hole from the inside of the box with the circle of cardboard cut out in STEP 2 and attach it with a brass fastener. The cardboard vent door should be free to rotate around the brass fastener and thereby open and close the vent. A handle can be made for this vent door by folding a piece of tape in half leaving the ends open to stick to the new door. Attach the tape to the right side of the door with it closed all of

the way. This will allow you to open and close the door and adjust the air (in the plenum) that goes into the fluid bed.

6. Close the box and seal the edges with tape, leaving only the vent and hair dryer discharge holes untapped.

7. Cut a circle of screen about 6 cm larger in diameter than the diameter of the second 2-liter soda bottle. Tape this screen to the top of the bottle section. This section will act as a filter to keep the fluid bed contained within the plastic bottle sections.



8. Place 2 cups of puffed rice into the 2 liter container attached to the plenum (box).

9. Fit the two plastic bottle sections together so that they form a tube with the screen at the top.

10. Install hair dryer, open the vent door on the side of the plenum (box) as far as it will go, and turn on the hair dryer. Use the cold setting on the dryer. Dryers with only warm or hot settings should not be used as the dust from the cereal may pose a fire hazard.

11. Air flow through the puffed rice bed is regulated by opening and closing the vent door on the side of the plenum. Opening the door allows air to escape the plenum and reduces the amount of air through the bed. Closing the door increases the amount of air through the bed. Increasing the amount, and hence the velocity, of air through the bed causes channels between the cereal pieces to enlarge and the particles become more separated. As this occurs, the puffed rice takes on the appearance and many of the properties of a liquid. The bed is said to be fluidized. If the material clumps, it will form an open, stable channel of sufficient size so as to allow most gas to flow through.



## ACTIVITIES

Have students feel the texture of the rice as the air flows through, then turn the air off. Notice the change in texture. You may wish to substitute a three liter bottle so students will have more area to insert their hand to feel the rice.

Turn off the dryer and place a cotton ball and one of the lids from the 2-liter soda bottles on the “puffed rice” bed. Turn on the dryer and notice what happens to the cotton ball and the lid.

- What floats?
- What sinks?
- Does it sink without the air? What happens when the air is added to the bed?

Too much air will cause the bed to spout or channel along the sides. (This can be changed by lessening the air by opening the hole cut to regulate the air in the plenum.)

## Advanced Lessons:

**You may wish to demonstrate a simple manometer.** A manometer can be used to measure air pressure. Cut a small hole in the plenum (box). Place one end of the 1/4" clear plastic tubing in the hole and tape it into place. Tape the other end of the clear tubing to the side of a ruler and place this into a clear sided container of water. The ruler should be straight up and down in the water. With the dryer turned off, the water level in the plastic tubing will be at the same level as the rest of the water in the container. When the dryer is turned on, the water in the tube will be forced down by the air pressure in the plenum. Higher pressures cause the water to be forced further down the tube. The ruler allows the distance the water moves in the tube to be measured. Every inch that the water is displaced in the tube equals 0.036 Pounds per Square Inch (psi).

- Using the manometer, measure the pressure in the plenum when the puffed rice just starts to move and become fluidized.
- How much does the pressure change as the rice is fluidized further?

**Try Grape Nuts in the fluidized bed.** Replace the bed with Grape Nuts cereal. Turn on the hair dryer and measure the pressure within the plenum.

- How does the pressure compare to the pressure in the plenum when the puffed rice bed was used?
- Why is there a difference in pressures between the two beds.

**Try Rice Krispies in the fluidized bed.** Replace the puffed rice with Rice Krispies. You will be able to clearly see what is meant by the term *finer*. Rice Krispies break up by *attrition* into smaller pieces that can make a mess.

## Fluidized Bed ----- VOCABULARY STUDY GUIDE

Name \_\_\_\_\_ Date \_\_\_\_\_

Directions: Using the Glossary, complete the study guide by filling in blanks with the appropriate terms.

1. Wear that is caused by rubbing or friction is called \_\_\_\_\_.
2. The burning of gas, liquid or solid, in which fuel is oxidized involving heat and often light is \_\_\_\_\_.
3. What is a fluidized bed?
4. The ability of a membrane or other material to allow a substance to pass through it is \_\_\_\_\_.
5. Pressure is the type of stress which is exerted \_\_\_\_\_ in all directions, its measure is the force exerted per unit area.
6. A characteristic or trait of an object is a \_\_\_\_\_.
7. What is spouting in a Fluidized Bed?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
8. Momentum is the \_\_\_\_\_ of the mass of an object and its velocity.
9. In physics, the tendency or force that causes two separate bodies to pull together is referred to as this \_\_\_\_\_.
10. What is ambient pressure?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
11. A barometer measures \_\_\_\_\_.

12. Reduction in volume of a substance due to pressure is \_\_\_\_\_.
13. Breaks in a medium which permit a solution to run through without having contact with active \_\_\_\_\_ groups elsewhere in the bed is \_\_\_\_\_.
14. Fines are \_\_\_\_\_ smaller than average in a mixture of \_\_\_\_\_ varying in size.
15. Explain what buoyancy is in a Fluidized Bed?

**Label the following diagram. 16.-20.**

**Enrichment:**

21. How will the Fluidized Bed Technology effect you in the future?

## Fluidized Bed

## Vocabulary Matching Quiz

Name \_\_\_\_\_

Date \_\_\_\_\_

**Directions:** In the blanks provided, write the letter that best describes the term.

\_\_\_\_\_ 1. *distributor plate*

\_\_\_\_\_ 2. *permeable*

\_\_\_\_\_ 3. *force*

\_\_\_\_\_ 4. *gravity*

\_\_\_\_\_ 5. *friction*

\_\_\_\_\_ 6. *impermeable*

\_\_\_\_\_ 7. *manometer*

\_\_\_\_\_ 8. *fluid resistance*

\_\_\_\_\_ 9. *pressure gradient*

\_\_\_\_\_ 10. *absolute pressure*

A. Force which opposes the relative motion of two bodies.

B. Force that draws all bodies toward the center of the earth.

C. Device which distributes air at the exact time.

D. Force exerted by a gas or liquid opposing the motion of a body through it.

E. Material that permits a substance to pass through it.

F. Difference in pressure between two points in a flow system.

G. Pressure above the absolute zero value that is obtained in an empty space.

H. Will not permit fluid to pass through it.

I. The influence on a body which causes it to accelerate.

J. A “U” shaped tube used to measure the difference between two fluid pressures.

**Teacher's key:**

**Fluidized Bed Vocabulary Study Guide**

1. Wear that is caused by rubbing or friction is called **attrition**.
2. The burning of gas, liquid or solid, in which fuel is oxidized involving heat and often light is **combustion**.
3. What is a fluidized bed?  
**A cushion of air or hot gas blown through the porous bottom slab of a container which can be used to float a powdered material as a means of drying, heating, quenching, calcining the immersed components.**
4. The ability of a membrane or other material to allow a substance to pass through it is **permeable**.
5. Pressure is the type of stress which is exerted **uniformly** in all directions, its measure is the force exerted per unit area.
6. A characteristic or trait of an object is a **property**.
7. What is spouting in a Fluidized Bed?  
**The feeding or ejection of powdered or granulated solids by means of vertical or slanted discharge spouts.**
8. Momentum is the **product** of the mass of an object and its velocity.
9. In physics, the tendency or force that causes two separate bodies to pull together is referred to as the **attraction**.
10. What is ambient pressure?  
**The pressure of the surrounding medium, such as a gas, or liquid, which comes into contact with an apparatus or with a reaction.**
11. What does a barometer measure?  
**Atmospheric pressure and is used in forecasting weather.**

12. Reduction in volume of a substance due to pressure is **compression**.
13. Breaks in a medium which permit a solution to run through without having contact with active groups elsewhere in the bed is **channeling**.
14. Fines are **particles** smaller than average in a mixture of **particles** varying in size.
15. Explain what buoyancy is in a Fluidized Bed?  
**The resultant vertical force exerted on a body by a static fluid in which it is submerged.**

Label the following diagram. 16.-20.

**Enrichment:**

21. How will the Fluidized Bed Technology effect you in the future?  
**Fluidized Bed Technology will enable us to efficiently use our fossil fuels to meet our energy and environmental needs.**

**Teacher's Key****Fluidized Bed****Vocabulary Matching Quiz**

C 1. *distributor plate*

E 2. *permeable*

I 3. *force*

B 4. *gravity*

A 5. *friction*

H 6. *impermeable*

J 7. *manometer*

D 8. *fluid resistance*

F 9. *pressure gradient*

G 10. *absolute pressure*

A. Force which opposes the relative motion of two bodies.

B. Force that draws all bodies toward the center of the earth.

C. Device which distributes air at the exact time.

D. Force exerted by a gas or liquid opposing the motion of a body through it.

E. Material that permits a substance to pass through it.

F. Difference in pressure between two points in a flow system.

G. Pressure above the absolute zero value that is obtained in an empty space.

H. Will not permit fluid to pass through it.

I. The influence on a body which causes it to accelerate.

J. A "U" shaped tube used to measure the difference between two fluid pressures.

**Scientific Definition  
(Teacher Expanded Definitions)**

**Glossary-----Fluidized Bed**

- absolute pressure** The pressure above the absolute zero value of pressure that is theoretically obtained in empty space or at the absolute zero of temperature. (Absolute pressure is determined by adding the pressure as read from a pressure gauge and adding the atmospheric pressure surrounding the gauge.)
- ambient pressure** The pressure of the surrounding medium, such as a gas or liquid, which comes into contact with an apparatus or with a reaction. (Pressure which pushes on all sides.)
- atmospheric pressure** The pressure at any point in an atmosphere due solely to the weight of the atmospheric gases above the point concerned. Also known as **barometric pressure**. (The weight of the atmosphere per square inch of surface; the pressure of 14.69 pounds per square inch exerted in all directions, at the sea level, by the atmosphere.)
- attraction** In physics, the tendency, force, or forces through particles, bodies, etc. that attract or pull together. (The inherent tendency of bodies to approach each other, to unite, and to resist separation.)
- attrition** Wear caused by rubbing or friction; for metal surfaces, also known as scoring; scouring. [*Attrit (v) to wear*] (The state or process of being gradually worn down.)
- barometer** An absolute pressure gage specifically designed to measure atmospheric pressure. (An instrument for measuring atmospheric pressure and thus for forecasting the weather or finding height above sea level.)

<b>barometric pressure</b>	See atmospheric pressure. Atmospheric pressure on a barometer. (A variation of atmospheric pressure.)
<b>barrier</b>	Any physical or biological factor that restricts the migration or free movement. (Anything that marks the limits of a place; any limit or boundary; a line of separation)
<b>buoyancy</b>	The resultant vertical force exerted on a body by a static fluid in which it is submerged or floating. (The upward pressure by any fluid on a body partly or wholly immersed therein; it is equal to the weight of the fluid displaced.)
<b>channeling</b>	Furrows or breaks in a medium which permit a solution to run through without having contact with active groups elsewhere in the bed. (That by which something passes or is transmitted; means of passing, conveying, or transmitting.)
<b>combustion</b>	The burning of gas, liquid, or solid, in which the fuel is oxidized, evolving heat and often light. (The act or process of burning.)
<b>compression</b>	Reduction in volume of a substance due to pressure. (The act of pressing or squeezing something together.)
<b>distributor plate</b>	Any device which distributes air at the exact time. (To scatter or spread out, as over a surface.)
<b>finer</b>	Particles smaller than average in a mixture of particles varying in size. (Small pieces torn from a substance, usually by rubbing.)
<b>fluid</b>	A substance (as a liquid or gas) tending to flow or take the shape of its container. (Like a fluid, that can change rapidly or easily; not settled; mobile or plastic.)

<b>fluidized bed</b>	A cushion of air or hot gas blown through the porous bottom slab of a container which can be used to float a powdered material as a means of drying, heating, quenching, or calcining the immersed components.
<b>fluidized-bed combustion</b>	A method of burning particulate fuel, such as coal, in which the amount of air required for combustion far exceeds that found in conventional burners; the fuel particles are continually fed into a bed of mineral ash in the proportions of 1 part fuel to 200 parts ash, while a flow of air passes up through the bed, causing it to act like a turbulent fluid.
<b>fluid resistance</b>	The force exerted by a gas or liquid opposing the motion of a body through it. Also known as resistance.
<b>force</b>	The influence on a body which causes it to accelerate.
<b>freeboard</b>	The space provided above the bed to allow for expansion of the bed.
<b>friction</b>	A force which opposes the relative motion of two bodies whenever such motion exists or whenever there exist other forces which tend to produce such motion. (The force of rubbing one body against another.)
<b>gauge pressure</b>	The amount by which the total absolute pressure exceeds the ambient atmospheric pressure. (Atmospheric pressure or water pressure measured using a gauge.)
<b>gravity</b>	The force that tends to draw all bodies in the earth's sphere toward the center of the earth.
<b>heat</b>	A form of energy whose effect is produced by the accelerated vibration of molecules; theoretically, at $-273^{\circ}\text{C}$ , all molecular vibration would stop and there would be no heat.

<b>impermeable</b>	Not permitting water or other fluid to pass through. Also known as impervious.
<b>intermolecular forces</b>	The force between two molecules. <b>Repulsion</b> is a force that tends to increase the distance between two bodies having like electric charges. <b>Attraction</b> is a force that causes adhesion. A cushion of air or hot gas blown through the porous bottom slab of a container which can be used to float a powdered material as a means of drying, heating, quenching, or calcining the immersed between objects. (The attraction or repulsion of molecules which leave a certain amount of space between them.)
<b>manometer</b>	A liquid-column gage (U-shaped) used to measure the difference between two fluid pressures. (An instrument, usually a U-shaped tube, for measuring the pressure of gases or vapors.)
<b>medium</b>	That entity in which objects exist and phenomena take place; examples are free space and various fluid and solids. (Any surrounding or pervading substance in which bodies exist or move.)
<b>momentum</b>	The quantity of motion of a moving object, equal to the product of its mass and its velocity.
<b>permeable</b>	The ability of a membrane or other material to permit a substance to pass through it. (Open to passage or penetration, especially by fluids.)
<b>plenum</b>	A condition in which air pressure within an enclosed space is greater than that in the outside atmosphere. (An enclosed volume of gas under greater pressure than that surrounding the container.)

<b>pressure</b>	A type of stress which is exerted uniformly in all directions; its measure is the force exerted per unit area. (Force exerted against an opposing body; the thrust distributed over a surface.)
<b>pressure gradient</b>	The change in pressure divided by the distance over which that pressure change occurs at a fixed time.
<b>property</b>	A characteristic or trait of an object. (Any trait or attribute proper to a thing, any of the principal characteristics of a substance.)
<b>spouting</b>	To flow or shoot out with force, forming a spout.

### **Website Addresses**

Visit these web sites for additional information:

[www.fetc.doe.gov/products/power/fbc.html](http://www.fetc.doe.gov/products/power/fbc.html)

[www.fe.doe.gov/coal\\_power/pfb\\_sum.html](http://www.fe.doe.gov/coal_power/pfb_sum.html)

[www.emperoraquatics.com/biofilter.shtml](http://www.emperoraquatics.com/biofilter.shtml)

[www.energyproducts.com/tech.html](http://www.energyproducts.com/tech.html)

[www.rainbow-lifeguard.com/fluidized-bed-main.htm](http://www.rainbow-lifeguard.com/fluidized-bed-main.htm)

[www.reaction-eng.com/design.htm](http://www.reaction-eng.com/design.htm)

There are many more available sites that you may wish to search. A good world wide web search engine can be found at:

[www.metacrawler.com](http://www.metacrawler.com)

Search for **fluidized bed** or **fluidized bed combustion**