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Fördelare av gaser i fluidiserad bädd
Distributor of gases in the bottom part of a fluidized bed

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by

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Summary

The invention concerns a device for distributing gases released from solid fuels in the bottom part of a fluidized bed. The device can be used in any fluidized bed for combustion or conversion of solid fuels, although the use would be especially advantageous in the fuel reactor of a chemical-looping combustor. The main principle of the device is an elongated box with an opening downwards. Gas released or inserted in the box will pass into the fluidized bed below the lower edge of the box and thus the box will distribute the gas in the bed.

Distributor of gases in the bottom part of a fluidized bed

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State of the art

WHAT IS CLC

Chemical-looping combustion (CLC) has emerged as an attractive option for carbon dioxide capture because CO_2 is inherently separated from the other flue gas components, i.e. N_2 and unused O_2, and thus no energy is expended for the gas separation and no gas separation equipment is needed. The CLC system is composed of two interconnected fluidized bed reactors, an air and a fuel reactor. Oxygen carriers in the form of metal oxide particles are used to transfer oxygen transfer between the two reactors. The general principle is shown in Fig. 1 and an example of how the process could be designed using the circulating fluidized bed principle for the transfer of particles between the two reactors is shown in Fig. 2. [*Fig. 1. Chemical-looping combustion.* Me_xO_y/Me_xO_{y-1} *denotes recirculating oxygen carrier material.*] [*Fig. 2. Example of process configuration using two interconnected fluidized beds where a high gas velocity in the air reactor (1) drives the circulation between the air reactor and fuel reactor (2), similar to the technology used in circulating fluidized beds. Fluidized loop seals prevent gas mixing between the two reactors (4).*]

CLC research and development initially had a focus on gaseous fuels, but in the last years important work has been dedicated to adapting the process to solid fuels. Technology overviews are given in a number of reviews, e.g.[1-4].

Chemical-looping combustion of solid fuels could use the general circulating fluidized bed (CFB) concept outlined in Fig.2, but the fuel reactor system would need to be adapted for addition of solid fuels.

In the case of gaseous fuels, these are introduced through the bottom plate as fluidizing gas, thus achieving a good distribution over the cross-section. As the gas moves upwards through the bed it is gradually converted and if conditions are suitable the gases are fully oxidized to CO_2 and H_2O as they leave the reactor, as has been shown in pilot testing with gaseous fuels like natural gas[5].

When using solid fuels, these release gaseous combustible compounds (volatiles) that may react with the oxygen carrier to form CO_2 and H_2O. After the volatiles release there is a remaining combustible solid char that also need to be burnt. The reaction between the oxygen-carrier and the char remaining after volatiles release is not direct, but involves an intermediate gasification step, Fig. 3. [*Fig.3. Principal reactions when using solid fuels in chemical-looping combustion.*]

Pilot testing with CLC and solid fuels[6], shows that high conversion, up to 95%, of the gas generated from the gasification of char can be reached, whereas the conversion of volatiles is considerably lower. Further, pilot testing has also shown that moving the location of fuel introduction from above the bed to a position well below the bed surface, results in a dramatic improvement of gas conversion.[7] This is expected, since fuel feeding above the bed will mean that most of the volatiles are released above the bed and will have little opportunity to react with the oxygen carrier. In the following conversion of volatiles will be in focus.

ANALOGY TO CIRCULATING FLUIDIZED BED COMBUSTION

The CLC process has important similarities to normal combustion of solid fuels in circulating fluidized bed (CFB) boilers. Thus, CFB combustion is an integral part of the state of art for CLC. In this context there are two important differences between normal fluidized bed combustion and chemical-looping combustion. Firstly, the fuel particles need to be small enough that it is largely gasified before it reaches the air reactor through the normal circulation of particles between the reactors. Secondly, the solid fuel needs to be introduced in the bottom part of the fluidized bed of the fuel reactor to make the reaction of volatile gases with the oxygen carrier possible. The small size of the particles mean that they will release volatiles rapidly when introduced in the bed, typically within 1 s. This is also advantageous as it means that the volatiles will be released in the bottom of the bed.

The problem

Existing pilots for this technology[3, 4, 8-12] use somewhat different approaches to feeding the solid fuels, but they all have in common that the solid fuel is inserted in one point. By different approaches are meant coal screws, pneumatic feeding, and introduction by mixing into a particle flow coming from a loop seal. However, all of these units have small cross-sectional areas, with fuel reactor cross-sections less than 0.12 m^2. If this technology is to be built in large scale, i.e. with thermal power of e.g. 1000 MW, the cross-section of the fuel reactor bed would be much larger, likely in the range 50-100 m^2. The consequence of feeding fuel into such a large cross section via one or a few feeding points, considering the rapid devolatilization of the fuel, is that a local plume of volatiles will form at the point of feeding, as illustrated by Fig. 4. [*Fig. 4. Illustration of the problem of having one fuel entry for a fluidized bed with large cross-section. Left: Sideview. Right: Top view.*] This plume can be expected to pass through the bed with insufficient contact with the oxygen carrier, thus giving poor conversion of the volatile gas to CO_2 and H_2O.

In order to have a good distribution over the cross-section, the fuel entry points should preferably be close to each other, giving a large number of these. However, it would have significant disadvantages to construct a fluidized-bed with the large number of fuel feeding points needed to properly distribute the volatiles over the cross section, one important being the high cost of fuel feed entries.

Problem solution

The solution to the problem is to combine the fuel feeding with a gas distribution system in the form of a gas distributor box with an opening downwards in the bed, see Fig. 5. [*Fig. 5. General principle of distributor box, i.e. a box with an opening downwards.*] Below this gas distributor box is referred to as the box. The gas is distributed by this box and will pass into the bed below the low edge of the box. In order to improve the gas distribution the lower part of the edge can have slits or holes where volatiles may enter the bed from the box.

Explanation to solution. Fluidized beds have properties that resemble liquids. Thus, if gas is introduced in a box that is immersed upside down in a fluidized bed the box will become filled with gas and have a bed surface at the bottom of the box, see Fig. 6. [*Fig. 6. Example showing how the box can be immersed in a fluidized bed with fuel feeding at the short side of the box. Left: cross-section side view. Right: view from top.*] It is well established in fluidization research that the particles, when fluidized will behave similar to a liquid and thus form a surface at the bottom of the box. The gas inserted will pass into the bed below the bottom edge of the bed, as illustrated by Figure 6. Thus the box will allow the volatiles, i.e. the gas released from the fuel as it is introduced in the box, to distribute along the length of the lower edge of the box.

Design considerations. Below a number of aspects of design of this distributor box will be considered.

Connection of box to fuel feeding. The fuel can be fed into the box on the short edge, as illustrated in Fig. 6, or, if the box is aligned along the wall, at the long edge, as illustrated in Fig. 7. [*Fig. 7. Example showing how the box can be immersed in a fluidized bed and attached to wall, with fuel feeding at the long side. Left: cross-section side view. Right: view from top.*] It would also be possible to feed the fuel from below into the box.

The fuel can be fed directly into the box using for instance a coal screw or pneumatic feeding, as in Figs 6 and 7. The coal can also be fed more indirectly into the bed together with a flow of particles coming into the bed, as in Fig. 8. [*Fig. 8. Example where the box is oriented along the wall and extended over an inlet flow of particles coming from a downcomer via a loop seal. Fuel is introduced in the particle flow on the outlet side of the loop seal. Left: cross-section side view. Right: view from top.*] Here the solid fuel is introduced to fall into the flow of solid material coming via the downcomer and loop seal. The box is extended over a bed that is not directly connected to the bottom bed. In Fig. 9 a similar approach is used, although the fuel is introduced to a separate box from which the gas is led into the distributor box as indicated by the right-hand arrow. [*Fig. 9. Example where the box is oriented along the wall. Fuel is introduced* *in the particle flow on the outlet side of the loop seal, and the box is not directly connected to the box where fuel is introduced.*] The box could also have larger width and/or height at the fuel introduction point, as illustrated by Fig. 10. [*Fig. 10. Example where the box is increased in size where the fuel is introduced.*] This is to assure that the gas released from devolatilization goes into the box and is distributed over the cross section.

Cross-section of box. The box could have various cross-section profiles. For instance an inclination of the roof is likely advantageous to avoid a zone of stagnant material on the upper side of the box. The side-walls does not necessarily need to be vertical. Examples are shown in Fig. 11. [*Fig. 11. Examples of varying cross-sections of the distributor box.*]

Inclined walls. It could be advantageous to design the bottom bed with inclined walls. Fuel feeding could then be done from the side at different levels, as indicated by Fig. 12. [*Fig. 12. Example of distributor boxes and fuel feeding being attached to a sloping bottom bed wall.*]

Slits/holes in side walls of box. If the box is elongated and thus has a long edge, and considering the pressure fluctuations typical of fluidized beds, there is a risk that pressure fluctuations in the fluidized bed will cause the gas to leave the box locally in a batch-wise manner and contribute to form larger local bubbles. This could then decrease the efficiency of the gas distribution over the cross-section. In order to assure a good distribution over the cross-section it is possible to design the box with slits or holes along the side wall, as illustrated in Fig. 13. [*Fig. 13. Examples of slits and holes along the side of the box to promote gas good gas distribution. 1st and 2nd from left: Two examples of slits. 3rd from left: Holes instead of slits. Right: both holes and slits.*] This will facilitate the mixing into the bed and distribution over the cross-section, because gases will leave the box in a more controlled manner.

In order to further secure the distribution over the cross-section, and considering local pressure variations caused by bubbles, it is possible to vary the height of the slits, as illustrated in Fig. 14 (left). [*Fig. 14. Left: Slits with varying heights. Right: slits with interruptions to improve structural strength of box.*] It is also possible to use a variation of height and distribution of slits to control where the gas is released. Thus, depending on where and how fuel is fed and where and how oxygen carriers are supplied and removed from the bed, it could be advantageous to increase the release of volatiles in some parts of the bed and suppress it in others, e.g. close to fuel feeding.

Moreover, the structural strength of the box can be improved by interruptions or bridges in the slits, as illustrated by Fig. 14 (right). The slits will make the bed surface below the box rise to a higher level, see Fig. 15. [*Fig. 15. If the box has slits/holes where gas can leave, the pressure in the box will decrease and the bed surface will rise to a level pressure balance is attained.*] The higher level of the bed inside the box will reduce the risk that gas is released below the bottom edge in an uncontrolled way and promote a more controlled distribution of gas into the bed via the slits. The bed level attained inside the box will be dependent on the flow of gas that is to be released from the box, as well as the design of the slits/holes.

Dimensions of box. The cross-section, i.e. height and width of the box, should be sufficient to give a minimal pressure drop for the gas to pass from one fuel entry point to the far end of the box. Further, the height of the box should also be sufficient both to accommodate for slits. The length of the box is determined by cross section that the volatiles should be distributed over. The box could have bends and branches to allow a low number of feeding points to serve a large cross-section as illustrated in Fig. 16. [*Fig. 16. Example showing how distributor boxes can be used to distribute volatiles over a large cross section. Left: top view. Right: cross-section side view showing the totally six arms of the boxes immersed in the lower part of the bed.*]

Support of box. The box can be either supported by a side wall, or, if it protrudes into the bed from the wall by suitable legs.

Fines and syngas. Although the main purpose of the box is distribute gases from devolatilization of solid fuel, it could also improve the distribution of char and gas from char gasification. Firstly, if the fuel introduced contains fines, these fines may follow the gas stream in the box, and in this way become better distributed over the cross-section. Secondly, and depending on how the fuel is introduced, cf. Figs 7-9, the fuel particles after releasing volatiles, may also have time to start to gasify before they are mixed into the bed. The syngas thus produced will mix into the gas in the box and also achieve a better distribution over the cross-section.

Acknowledgement

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Description of Figures

Fig. 1. Chemical-looping combustion. Me_xO_y/Me_xO_{y-1} denotes recirculating oxygen carrier material.

Fig. 2. Example of process configuration using two interconnected fluidized beds where a high gas velocity in the air reactor (1) drives the circulation between the air reactor and fuel reactor (2), similar to the technology used in circulating fluidized beds. Fluidized loop seals prevent gas mixing between the two reactors (4).

Fig. 3. Principal reactions when using solid fuels in chemical-looping combustion.

Fig. 4. Illustration of the problem of having one fuel entry for a fluidized bed with large cross-section. Left: Sideview. Right: Top view.

Fig. 5. General principle of distributor box, i.e. a box with an opening downwards.

Fig. 6. Example showing how the box can be immersed in a fluidized bed with fuel feeding at the short side of the box. Left: cross-section side view. Right: view from top.

Fig. 7. Example showing how the box can be immersed in a fluidized bed and attached to wall, with fuel feeding at the long side. Left: cross-section side view. Right: view from top.

Fig. 8. Example where the box is oriented along the wall and extended over an inlet flow of particles coming from a downcomer via a loop seal. Fuel is introduced in the particle flow on the outlet side of the loop seal. Left: cross-section side view. Right: view from top.

Fig. 9. Example where the box is oriented along the wall. Fuel is introduced in the particle flow on the outlet side of the loop seal, and the box is not directly connected to the box where fuel is introduced.

Fig. 10. Example where the box is increased in size where the fuel is introduced.

Fig. 11. Examples of varying cross-sections of the distributor box.

Fig. 12. Example of distributor boxes and fuel feeding being attached to a sloping bottom bed wall.

Fig. 13. Examples of slits and holes along the side of the box to promote gas good gas distribution. 1st and 2nd from left: Two examples of slits. 3rd from left: Holes instead of slits. Right: both holes and slits.

Fig. 14. Left: Slits with varying heights. Right: slits with interruptions to improve structural strength of box.

Fig. 15. If the box has slits/holes where gas can leave, the pressure in the box will decrease and the bed surface will rise to a level pressure balance is attained.

Fig. 16. Example showing how distributor boxes can be used to distribute volatiles over a large cross section. Left: top view. Right: cross-section side view showing the totally six arms of the boxes immersed in the lower part of the bed.

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Claims

1. An arrangement of in-bed feeding of solid fuels in a fluidized bed characterized in a device in the form of an elongated box with a downward opening that contributes to the distribution of gases released from the fuel relative to the horizontal cross-section of the bed. One or more boxes which may be branched and/or have bends are used to achieve the distribution of gas over the cross-section.

2. An in-bed feeding of fuels according to claim 1, wherein the side walls of the box have slits or holes to promote an even distribution of gases over the cross-section.

3. An in-bed feeding of fuels according to any of claims 1 to 2, wherein the fuel feeding is directly into the box.

4. An in-bed feeding of fuels according to any of claims 1 to 2, wherein the fuel is fed in-directly into the bed with a flow of particles entering the bed, in such a way that the gas released enters the box.

5. An in-bed feeding of fuels according to any of claims 1 to 2 or 4, wherein the fuel is fed in-directly using a separate chamber from which the gas is led to the distributor box.

6. An in-bed feeding of fuels according to any of claims 1 to 5, wherein the box is enlarged around the fuel feeding point.

7. An in-bed feeding of fuels according to any of claims 1 to 6, wherein the box has a sloped upper side or sloped side walls.

8. An in-bed feeding of fuels according to any of claims 1 to 7, wherein slits or holes in the side walls box have a variation in height to secure good gas distribution over the whole cross-section.

9. An in-bed feeding of fuels according to any of claims 1 to 8, wherein slits in the side walls are interrupted by bridges to improve the structural strength.

10. An in-bed feeding of fuels according to any of claims 1 to 9, using a fuel with a volatiles content of 10-80%.

11. An in-bed feeding of fuels according to any of claims 1 to 10, where fine solid fuel is fed pneumatically and the box also contributes to the distribution of fuel particles over the cross section.

12. An in-bed feeding of fuels according to any of claims 1 to 11, where the fluidized bed is a fuel reactor of a chemical-looping combustor.

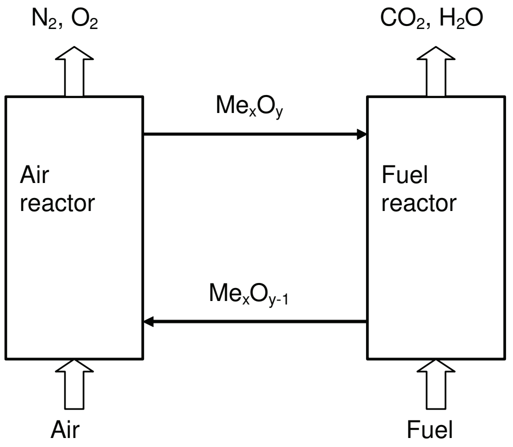
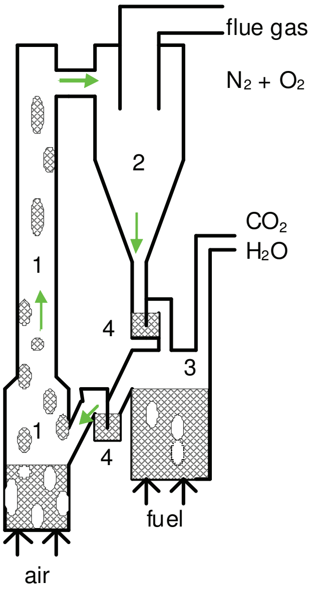


Figure 1.



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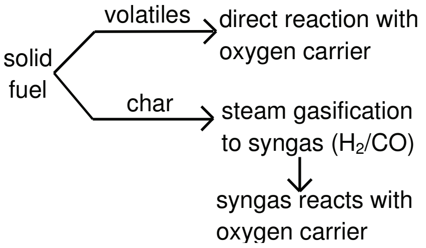

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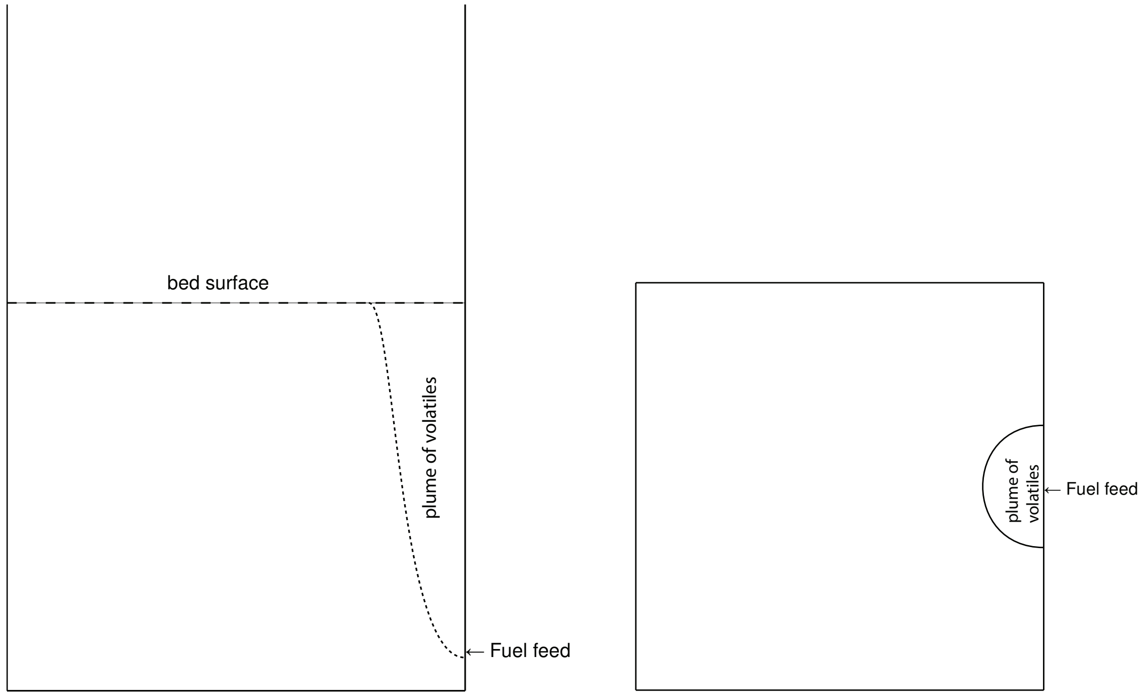

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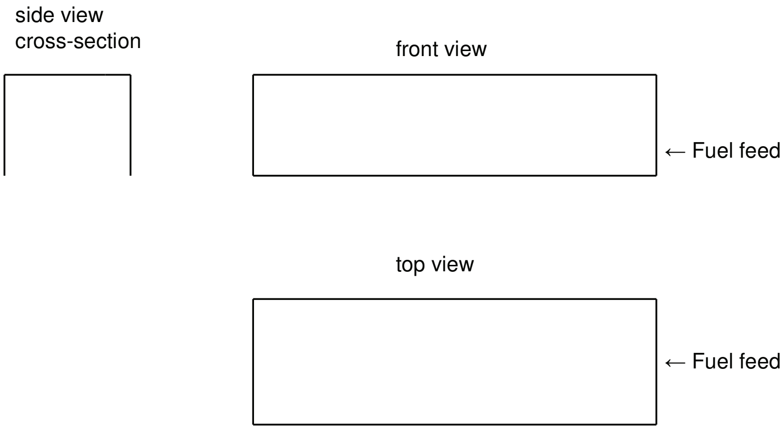

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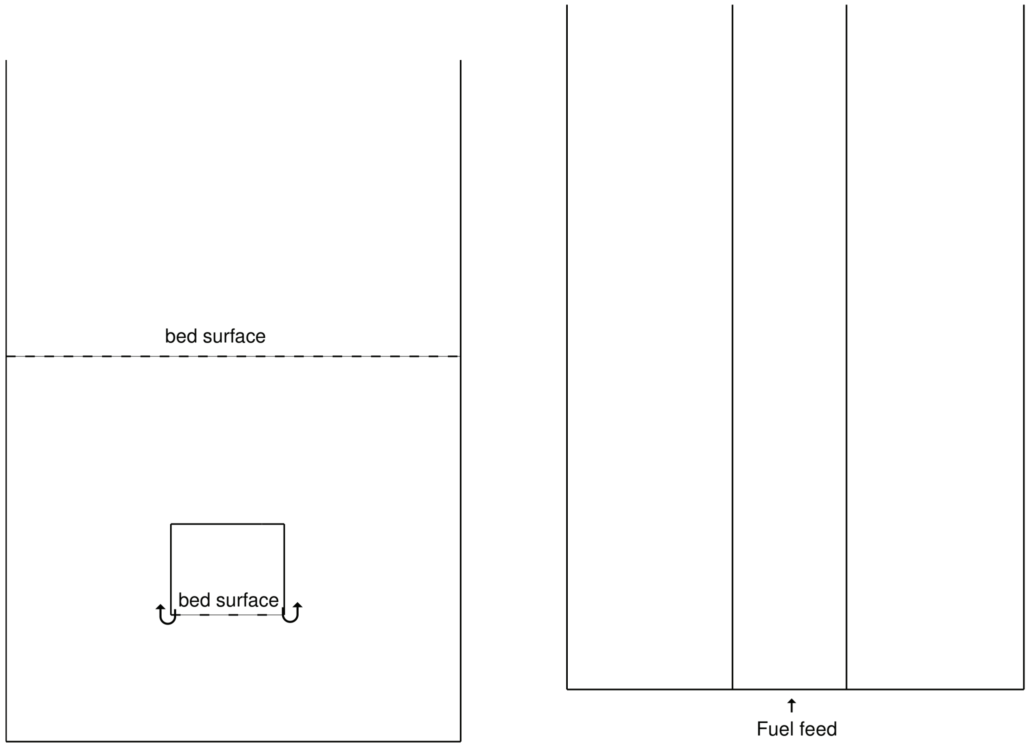

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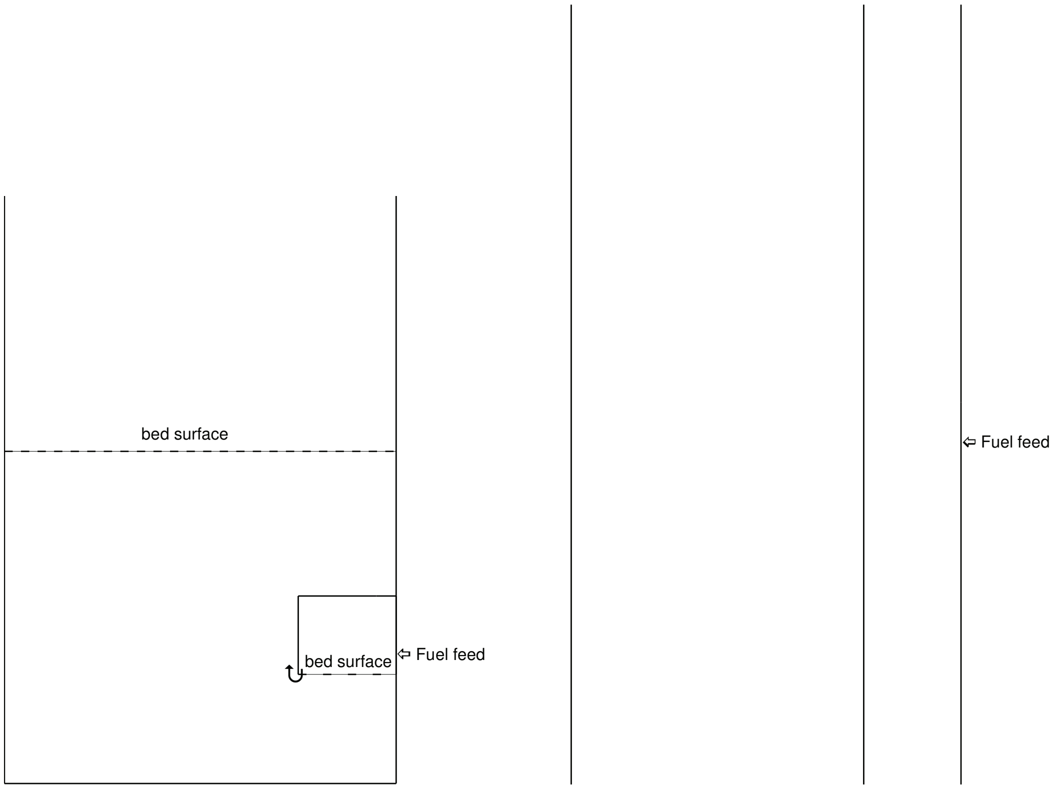

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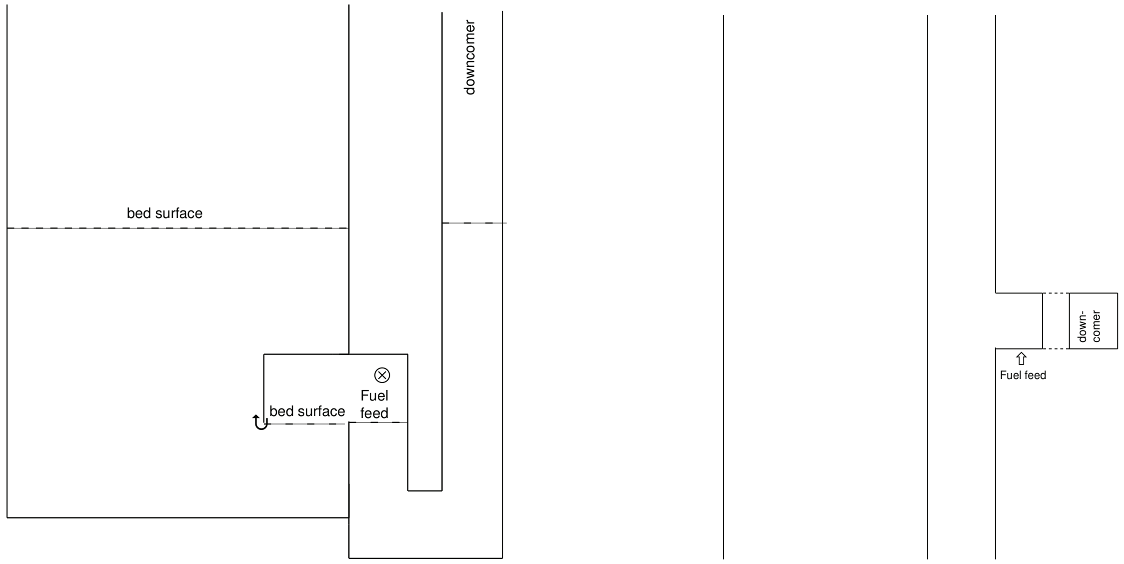

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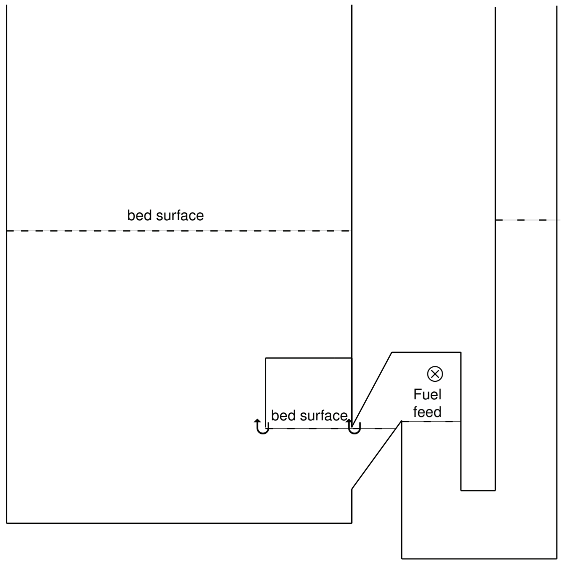

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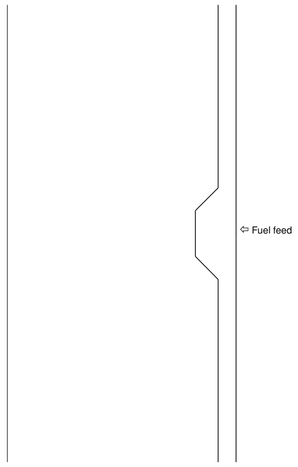

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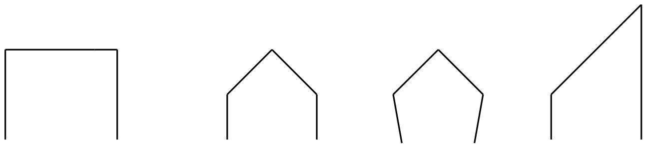

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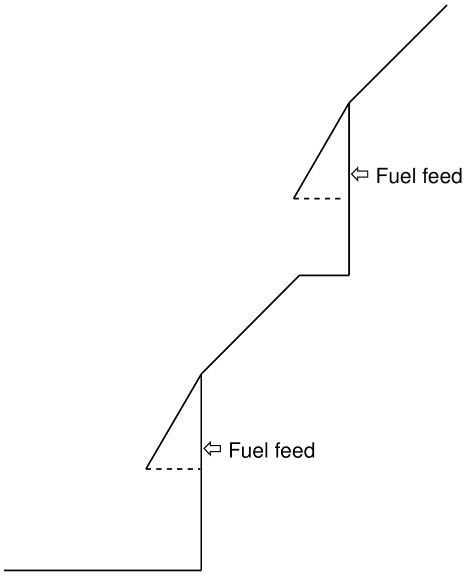

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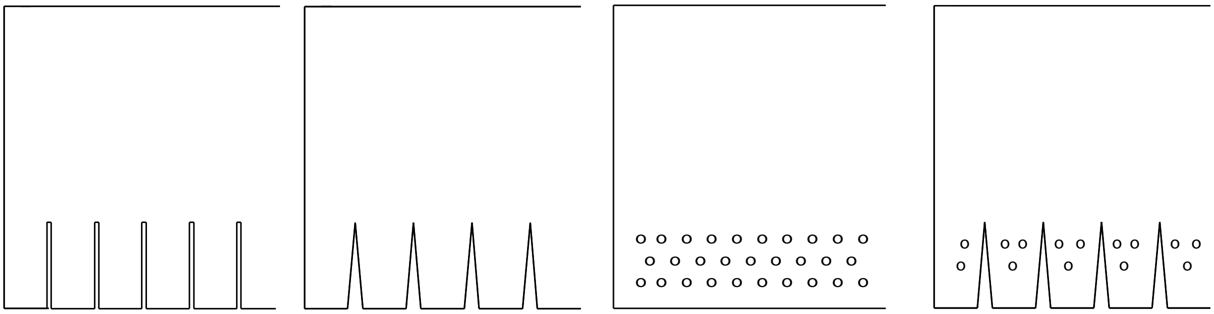

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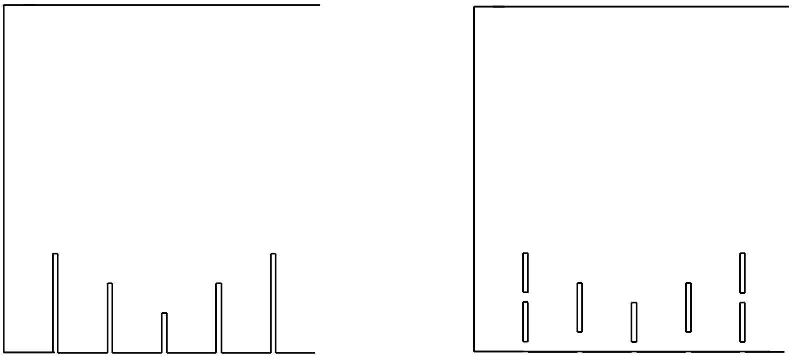

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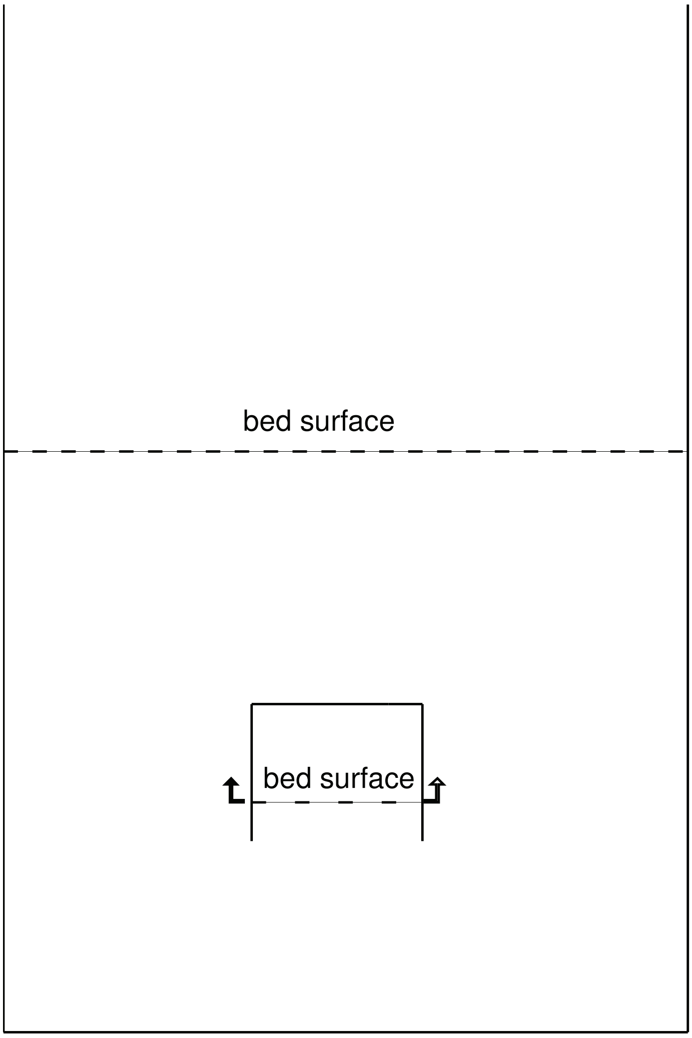

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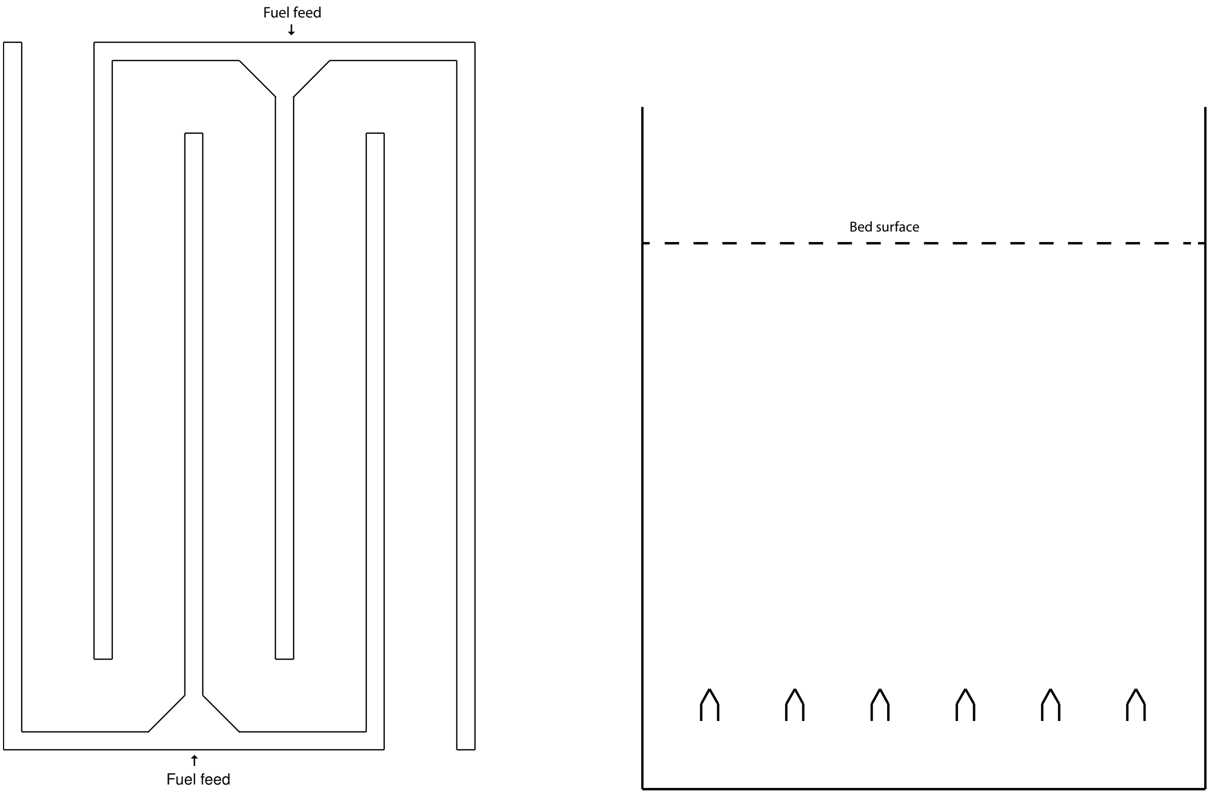

Figure 16.