In: BioCycle, December 2002, S. 34-36

PLANNING AND CONSTRUCTION OF BIOGAS PLANTS FOR SOLID WASTE DIGESTION IN AGRICULTURE

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Summary

There are about fifteen years of experience in the planning and construction of farm-scale biogas plants in Germany. During this time about 2,000 on farm biogas plants have been established. This is primarily due to available funding and mandatory favourable payment for each kWh delivered to the public energy grid. In general, three different kinds of digester types are in use for anaerobically treating manure and other organic input substrates. They are: small horizontal digesters, medium-sized upright concrete ones and large upright steel digesters. Several things must be known before the engineer can select the most suitable process technology and design the biogas plant. A great variety of technical solutions are available, however, their successful implementation frequently depends on the experience of the engineering and construction companies.

Keywords: biogas, farm-scale biogas plant, digester, anaerobic process technology

1. INTRODUCTION

By the mid-eighties, the first biogas plants for the digestion of animal manure were constructed in Germany. Denmark and East Germany with their large centralised farms, focused on large biogas plants; whereas in West Germany mainly independent farm-scale biogas plants were constructed. In the early eighty's the circumstances were very difficult, as there was no funding and no payment for the energy produced. Although there had been two previous major efforts – just after World War II and during the oil-crisis – only a few dozen plants had been

established by the mid-eighties. After getting off to a slow start in the late eighty's, the biogas business gradually began to grow. In the nineties the implementation of two very important regulations in Germany favoured the economic and technical success of renewable energy in general and biogas plants in particular.

During the past 15 years German engineers have a great deal of experience in the planning and construction of biogas facilities. Around 2,000 biogas plants will be in operation in Germany by the end of 2002. Most of these operate with manure and additional organic wastes (cofermentation) but the digestion of crops grown specifically for energy like corn, beets or grass is becoming increasingly important.

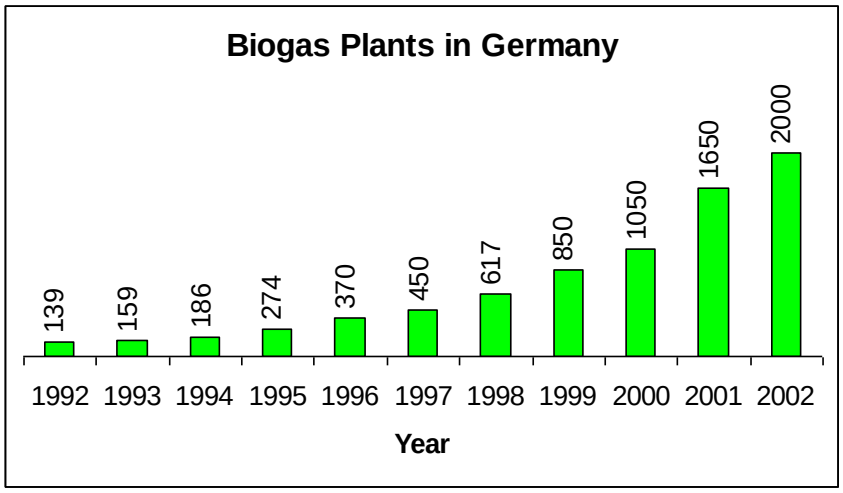

Figure 1: Development of Biogas Plants in Germany 1992-2002

Like the most developed countries German farms come in all sizes. For example in Southern Germany, in Bavaria and Baden-Wurttemberg, small farms with 100 cows and/or 500 pigs or even less are still common. In Northern Germany the farms tend to be larger. It is common to see several hundred cattle or over one thousand hogs on these farms. In Eastern Germany extremely large farms are in operation. These farms were developed after WWII and many have several thousand cows and sometimes tens of thousands of pigs. Naturally, the amount of manure produced corresponds to the number of animals. As a result farm-scale biogas plants in Germany can have a manure input of between 1,000 m³/a and 70,000 m³/a.

These significant differences in the volume of input from farm to farm require a variety of different specific digester technologies. However, in principle, all farm-scale biogas plants are the same.

2. BASIC LAYOUT OF A BIOGAS PLANT

Basically, each biogas plant includes the same principle components: a digester, a gas holder, a gas engine, tubes, mixers, etc. The rough layout is shown in Figure 2.

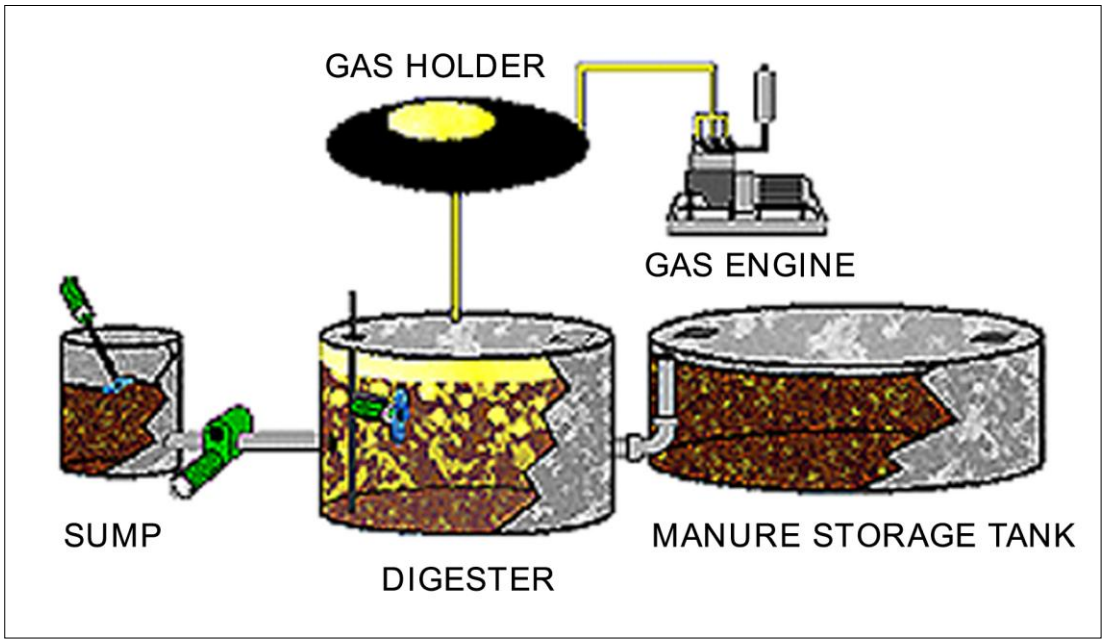

Figure 2: Basic Layout of a Biogas Plant

3. PLANNING AND CONSTRUCTION OF DIGESTERS

3.1 Horizontal Digesters

The smallest biogas plants are often constructed using a horizontal digester, Figure 4. They are made of steel and have a volume between 50 and 150 m³. The diameter is from 3.20 to a maximum of 3.50 m so they can be transported on German streets without additional costs. The final assembly is performed on site.

This type of tank is well-suited for treatment of dung and poultry manure as there are very good mixing conditions even for solids. Grit removal is easy to accomplish. This digester type cannot be transported in large sizes so it is most suitable for small farms.

3.2 Upright Standard Agricultural Digester

The standard digester in German biogas industry is the upright, cast in place concrete digester, Figure 4. The standard size of these units is between 500 and 1,500 m³. The height is often between 5 and 6 m; the diameter varies between 10 and 20 m.

The tanks are equipped with a heating system which circulates hot water through tubes fixed along the walls. The mixer is either completely immersed or equipped with a motor located outside the tank as shown in Figure 4. Large tanks are equipped with two or more mixers. The top of the tank is fitted with a double-membrane, gas-holder roof. The inner membrane is the gas-holding buffer; the outer membrane is the weather cover. The inner membrane is flexible in height; whereas the outer one is always ball shaped, as there is a blower which maintains a constant slightly elevated air pressure in the space between the two membranes in a manner similar to that used to support an air structure. The hydraulic retention time is generally between 30 and 80 days depending on the input substrate.

This type of tank is well-suited for every kind of input substrate as long as the flow rate is low enough. Grit removal is not a problem if there is a special device for mechanically removing. To accommodate this equipment some tanks are equipped with a concrete roof.

This type of digester is used for the treatment of up to 10,000 m³ input per year.

3.3 Upright Large Digester

For large quantities of input substrate, for example more than 30,000 m³ per year, large upright digesters are in use. In most cases the tanks are made of glass-coated prefabricated steel plates, or sometimes concrete is used. The standard size is between 1,000 and 5,000 m³. The height is often between 15 and 20 m; the diameter varies between 10 and 18 m.

The mixing is done by a mixer centrally located on the roof, which is in continuous operation. The input substrate is pre-heated before entering the digester. The hydraulic retention time is generally 20 days for manure. This shorter retention time can be achieved because of the advantages of pre-heating and continuous mixing.

This type of digester is used for the treatment of up to 90,000 m³ input per year per single unit. Large centralised digestion plants often have two or more tanks.

4. GAS ENGINE

In a standard farm-scale biogas plant in Germany there will be an engine to produce electricity and hot water from the biogas. There are basically two solutions for the question of what kind of engine will be chosen.

4.1 Gas Engine

For larger farm-scale biogas plants the pure gas engine will be the standard solution. This engine is based on an Otto engine (spark ignition) and is the same standard engine that is used for landfill and sewage gas treatment.

Depending on the circumstances on site, for example its heat use requirements, the use of such an engine is economically feasible for biogas plants with an electrical power of more than 150 to 200 kW. The electrical efficiency will be higher than 34%, and the investment will be a bit larger than for a dual fuel engine but the useful life and therefore the write-off period is longer.

4.2 Dual Fuel Engine

This kind of engine is based on a diesel engine and has to use up to 5 to 15% diesel fuel of the overall energy input. It is necessary to inject a small amount of diesel fuel (10%) at the point the biogas (90%) is compressed by the piston to achieve a good biogas burn.

Even for small engines the electrical efficiency is between 33 and 37%. This is extremely important for the economy of smaller farm-scale biogas plants in Germany as the farmer earns money mainly with the production of electricity.

Another advantage of this type of engine is the fact that they can be operated with diesel fuel alone. To start-up a biogas plant hot water is required to heat the digester contents. A dual fuel engine can be initially operated with diesel fuel to produce hot water until the biogas production starts. Then the diesel fuel can be turned down as the biogas production increases. Even low-quality biogas with a poor methane content can be utilised by a dual fuel engine. For a gas engine a

second gas source must be provided for start-up. For example natural gas or propane gas. Alternatively an extra boiler must be installed to provide heat for the digester.

The largest dual fuel engines available on the market have an electrical power output of 250 kW. At the upper end of this range the disadvantages gradually become important. For example the high consumption of diesel fuel and the fact that the electrical efficiencies of gas engines are similar to those of dual fuel engines have to be given careful consideration.

5. GAS HOLDER

There are several different kinds of gas holders available. But basically three of those are used most often:

- Balloon-shaped external gas holders. These are constructed from a flexible membrane and are often located under a simple roof, for example a car-port.
- Gas holder roofs. They are installed on top of a (concrete) digester. The cheap version is just a single membrane the better version is a double membrane roof, figure 5.
- External gas holders. Constructed in a separate tank these gas holders have a volume of up to 5,000 m³.

6. SOLIDS INPUT DEVICES

To improve the gas production farmers in Germany are adding more and more agricultural input substrates that are grown specifically to feed the biogas plants. Depending on the region, this includes corn and grass silage, grain, etc. Special solid input devices have been developed that enable the farmer to feed these solids directly into the digester.

Various kinds of solids input devices have been developed. Figure 3 shows one typical example.

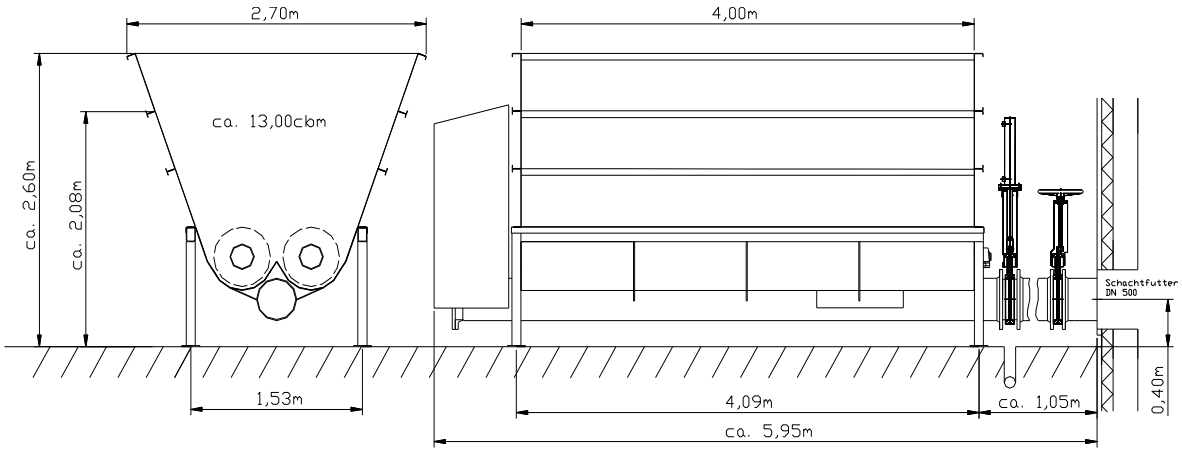

Figure 3: Example for Solids Input Device

7. RESULTS

Most of the biogas plants in Germany are medium-sized farm-scale biogas plants. The process temperature in general is mesophilic, and the process technology is one-staged. This plant type has been constructed more than 1,000 times with digester sizes between 300 and 1,500 m³. Several hundred small farm-scale biogas plants are equipped with horizontal digesters, mainly in South Germany. A few dozen biogas plants have been constructed with large upright digesters equipped with external heat exchangers and centrally located mixers.

There are large differences among all these farm-scale biogas plants. Besides variation in the types of digester, engine, gas holder and solids input device, there is a great variety of technical solutions for the degree of automation, the mixing procedure, the heat input, the feeding rate, the process temperature, etc.

Horizontal Digester

(50 – 150 m³ Volume)

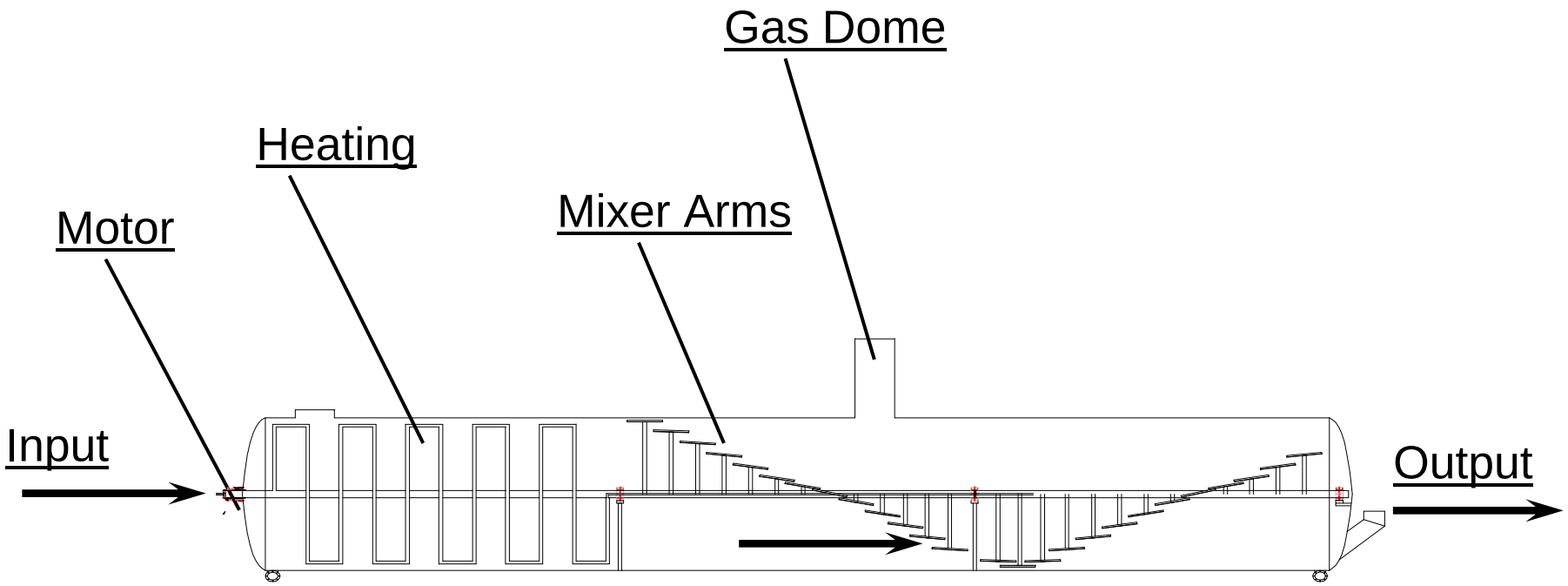

Figure 4: Horizontal Digester

Standard Digester in Agriculture

(up to 1.000 m³ Volume)

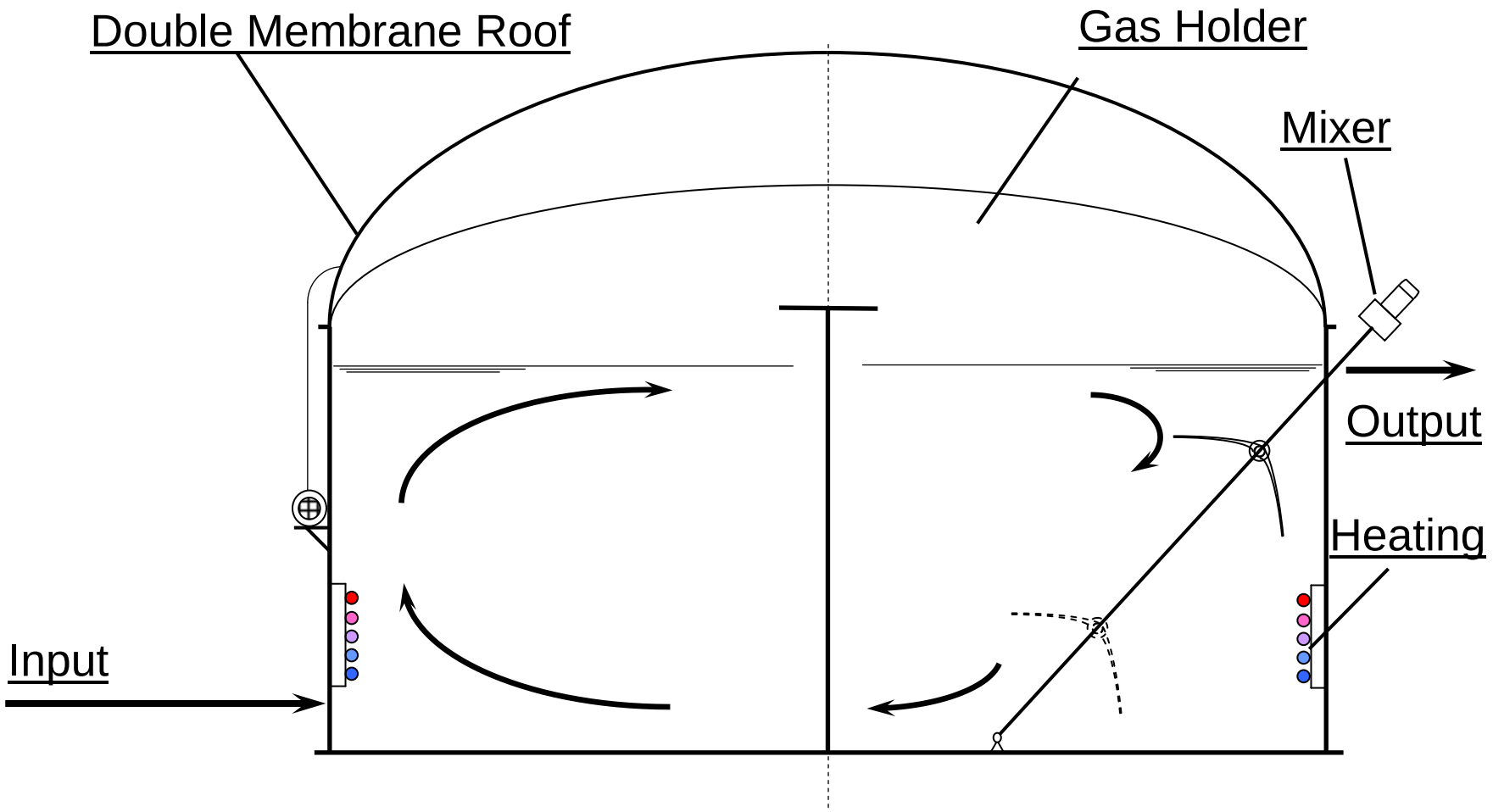

Figure 5: Standard Digester in Agriculture

Upright Large Digester

(up to 5.000 m³ Volume)

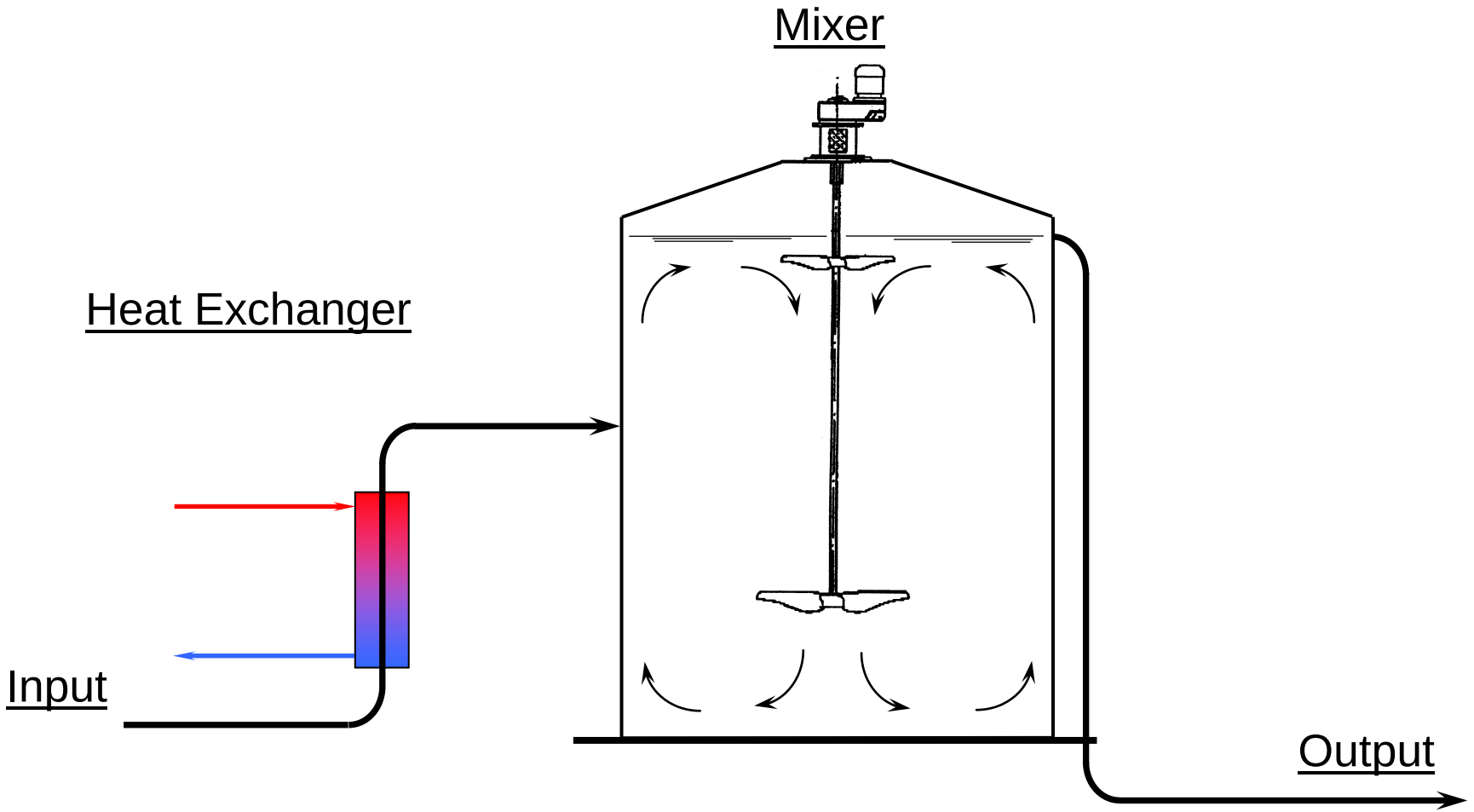

Figure 6: Upright Large Digester