FARM-SCALE BIOGAS PLANTS

Torsten Fischer, Andreas Krieg
Krieg & Fischer Ingenieure GmbH
Hannah-Vogt-Strasse 1, D-37085 Goettingen, Germany
phone: +49 551 3057432
Fischer@KriegFischer.de
www.KriegFischer.de

SUMMARY

In Germany there are about fifteen years of experience in the planning and construction of farm-scale biogas plants. In the meantime, approximately 1,600 biogas plants are in operation on farms. This is primarily due to investment funding and 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: small horizontal digesters, medium-sized upright concrete ones and large upright steel digesters. Depending on several factors, which have to be known before engineering of the biogas plant is begun, an experienced engineer chooses the most suitable process technology. This allows for a great variety of technical solutions, and their successful implementation frequently depends on the experience of the engineering and construction companies.

1. INTRODUCTION

In the mid-eighties, the first biogas plants for the digestion of animal manure were constructed in Germany. Denmark and East Germany focused on large centralised biogas plants; whereas in West Germany mainly farm-scale biogas plants were constructed at first. But 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 – there had been no success in establishing more than approximately a few dozen plants until the mid-eighties. After getting off to a slow start, the biogas business gradually began to become successful. In the nineties the implementation of two very important regulations favoured the economic and technical success of renewable energy in general and biogas plants in particular in Germany.

Meanwhile, after approximately 15 years of biogas engineering work, German biogas engineers have a great deal of experience in the planning and construction of biogas. Around 1,600 biogas plants will be in operation in Germany by the end of 2001. Most of them are still operated with manure and additional organic wastes (cofermentation) but the digestion of energy crops like corn, beets or grass is becoming increasingly important.

And, what is a farm-scale biogas plant? There is no clear definition for this, but in this context it shall be a biogas plant which is strictly related to one single farm. In contrast to this, there are also biogas plants which are owned by two or three farmers and belong to several farms or even large community biogas plants which can digest all the manure of the farms located in a single municipality or county.

There is a great variety of farm sizes in Germany. In Southern Germany, for example in Bavaria and Baden-Wurttemberg, small farms with 100 cattle and/or 500 pigs or even fewer are still common. In Northern Germany, for example in Schleswig-Holstein and Lower Saxony the farms are larger. There are often several hundred cattle and some thousand pigs on the farms there. In Eastern Germany and in Western Lower Saxony really large farms are in operation, which sometimes have several thousand cattle and sometimes tens of thousands of pigs. The amount of manure produced corresponds to these numbers of animals. Farm-scale biogas plants can have a manure input of between 1,000 m³/a and 70,000 m³/a.

These significant differences in the amount of input require a variety of different digester technologies but, in principle, all farm-scale biogas plants are the same.

2. BASIC LAYOUT OF A BIOGAS PLANT

Basically, each biogas plant consists from the same principle components: a digester, a gas holder, a gas engine, tubes, mixers, etc. The rough layout is shown in Figure 1.

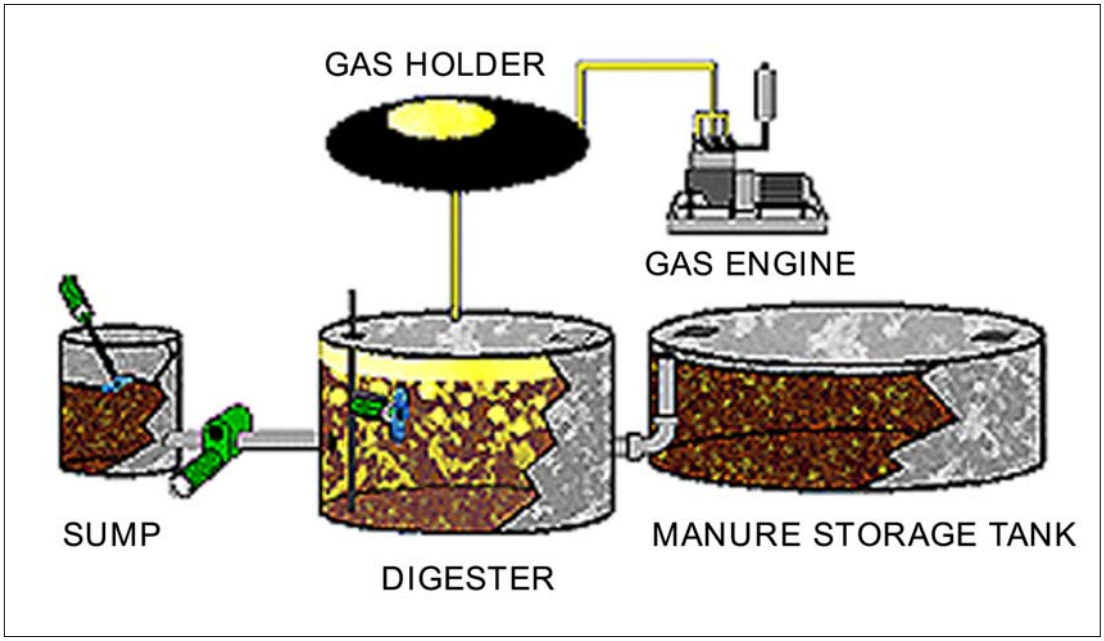

Figure 1: Basic Layout of a Biogas Plant

3. PLANNING OF BIOGAS PLANTS

The planning of biogas plants is generally not easy, as considerable data is required before engineering can begin. Above all, information has to be provided about the following:

- Type of input substrate
- Quantity of input substrate
- Local circumstances
- Heat use
- Pasteurisation
- Automation

Based on this data for each individual farm or each separate occasion, first the basic engineering that establishes the rough technical design of the plant has to be performed. The results of this design are as follows:

- Gas prognosis
- CHP-size (Combined Heat and Power Station – gas engine size)
- Digester size
- Flow-sheet
- Layout design
- Cost assessment

This includes the engineering office's decision about most appropriate process technology in each case. Depending on the input substrate, a process technology which enables the operator to run the biogas plant with the highest possible process stability has to be determined. Therefore, the decision has to be made between the following:

- Mesophilic and thermophilic Process Temperature

- One- and two-stage Processes
- Type of Mixing
- Type of Heat Input

The results of the planning determines which of the three major digesters types that are constructed in Germany will be implemented.

4. CONSTRUCTION OF DIGESTERS FOR FARM-SCALE BIOGAS PLANTS

4.1 Horizontal Digesters

The smallest biogas plants are often constructed with horizontal digesters, Figure 2. The material used is steel. Originally, old used tanks were taken to avoid unnecessarily high costs. These tanks were cleaned, reconstructed with central shafts, equipped with mixer arms, insulation, gas dome, etc., and re-used as a digester.

Today, the digester tanks are normally new and fabricated for use as a digester. Generally, the standard volume is between 50 and 150 m³. The breadth is 3.20 to a maximum of 3.50 m in order to be able to transport the tanks on German streets without additional costs. The final rigging is performed on site.

The hydraulic retention time is usually between 30 and 50 days, depending on the input substrate. The input is first heated by the heating arms, see Figure 2. When mesophilic temperatures are reached, the necessary mixing is done by standard mixing arms.

This type of tank is well-suited for treatment of dung and poultry manure as there are very good mixing conditions even for solids. Grid removal is unproblematical.

This digester type is comparatively cheap but cannot be transported in large sizes. This makes it most suitable for small farms.

4.2 Upright Standard Agricultural Digester

The standard digester in German biogas business is the upright, manufactured concrete digester, Figure 3. The standard size 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 delivers hot water into tubes fixed along the walls. The mixer is either completely immersed or equipped with a motor located outside the tank as shown in Figure 3. Large tanks are equipped with two or more mixers. On top of the tank is 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 hall. The hydraulic retention time is generally between 40 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. Grid removal is not a problem if there is a special device for mechanically removing this grid. For this reason 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.

4.3 Upright Large Digester

For large quantities of input substrate, for example more than 30,000 m³ per year, large upright steel digesters are in use. The steel is generally coated in order to avoid corrosion. In most cases glass-

coated prefabricated steel plates are used. The standard size is between 1,500 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 centrally located mixer on the roof, which is in operation continuously. The input substrate is pre-heated before entering the digester. The hydraulic retention time is generally 20 days. This short retention time can be chosen because of the advantages of continuous mixing and pre-heating.

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.

5. 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. Of course, there are other possibilities for using the biogas, for example pure hot water production or direct delivery of the biogas into a public natural gas network. There are research and development projects for fuel cells or biogas turbines. But in general – even on a long-term basis – the standard solution will be an engine. There are basically two solutions for the question of what kind of engine will be chosen.

5.1 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 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 write-off period is longer.

5.2 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. If this fuel is compressed by the piston and burns inside the cylinder the biogas (90%) burns, too.

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 operated with diesel fuel, produces hot water until the biogas production starts and then can be operated with biogas. Even low-quality biogas with any given methane content can be utilised by a dual fuel engine. For a gas engine – besides the biogas consumption – a second gas operation option must be found, for example natural gas or propane gas. Or an extra burner has to be installed.

The largest dual fuel engines available on the market have an electrical power output of 250 kW. At 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.

6. 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. They 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. Double membrane roofs are described in Chapter 4.2.
- External gas holders. In a separate tank there are gas holders with a volume of up to 5,000 m³. They are constructed such that either a complete balloon is enclosed in this tank or a half-balloon is integrated in the tank structure.

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 about 1,000 times with digester sizes between 300 and 1,500 m³. Several hundred biogas plants are equipped with horizontal digesters, mainly for small farm-scale biogas plants in South Germany. A few dozen biogas plants have been constructed with large upright digesters 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 and gas holder, 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)

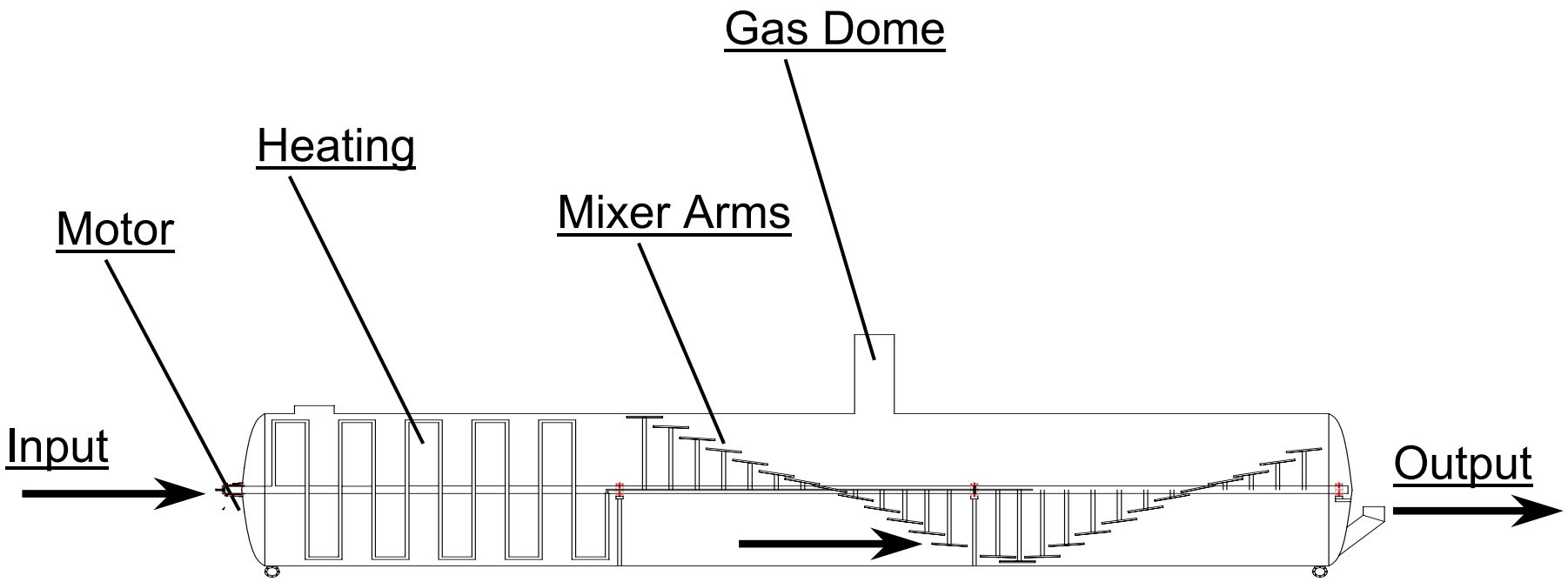

Figure 2: Horizontal Digester

Standard Digester in Agriculture

(up to 1.000 m³ Volume)

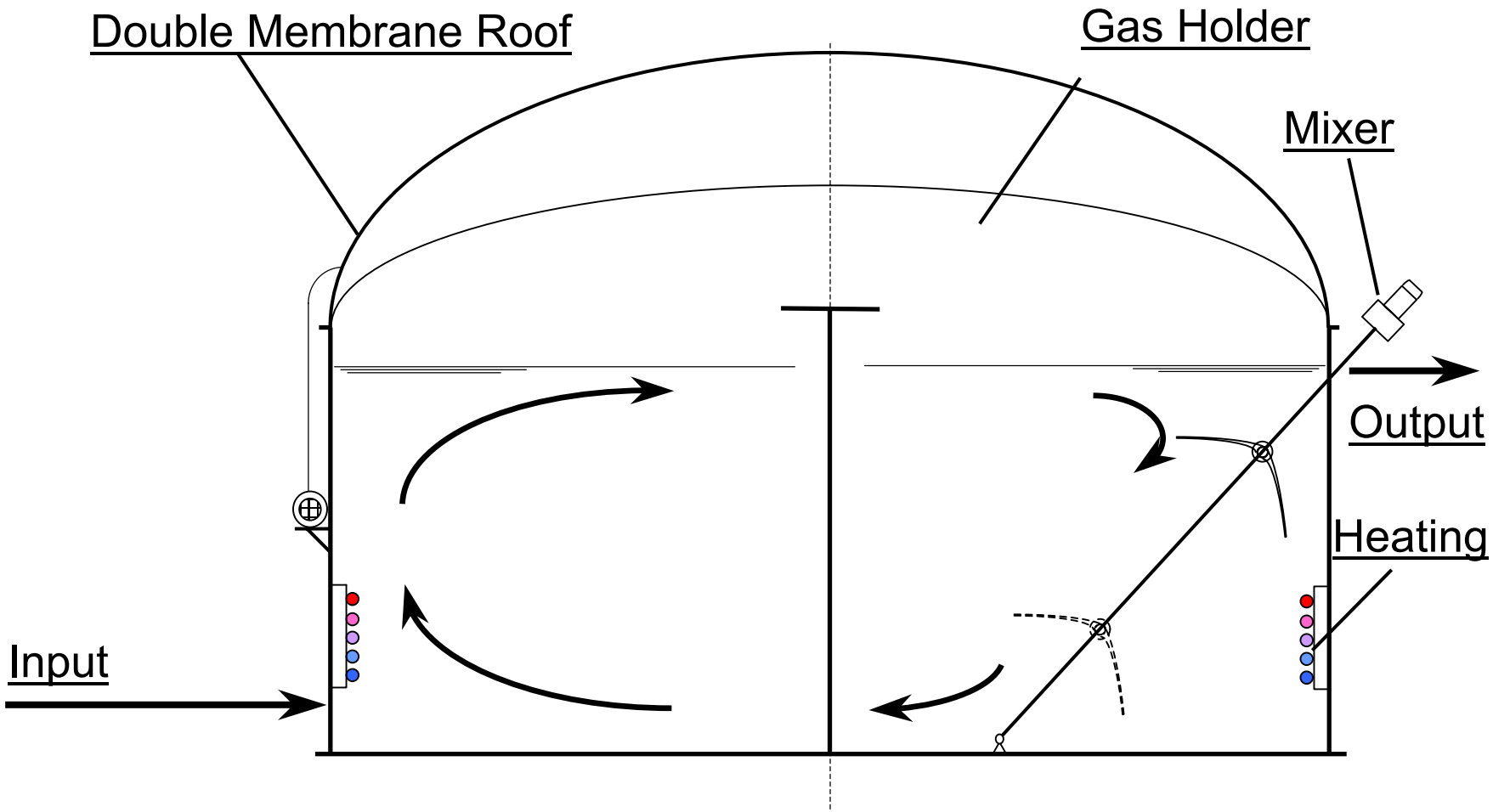

Figure 3: Standard Digester in Agriculture

Upright Large Digester

(up to 5.000 m³ Volume)

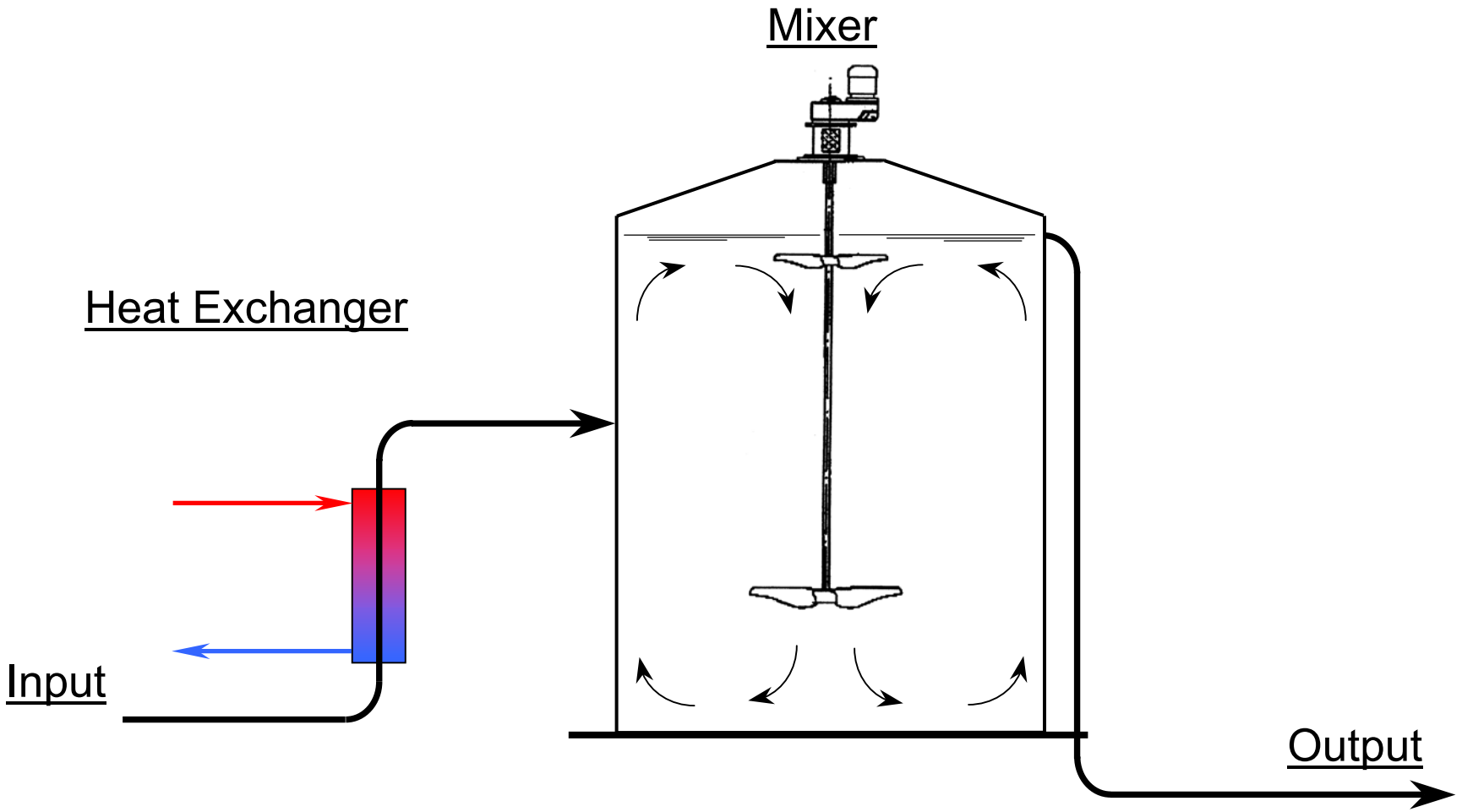

Figure 4: Upright Large Digester