Electroarc vapourtron for bitumen extraction and transportation

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Abstract. In this article, we propose the unique submersible arc vapourtron designed to generate very large amount of highly overheated water vapour. The most prospective application of such vapourtron is producing and processing of heavy oil and natural bitumen. The vapourtron represents an electroarc plasmatron using water or water vapour as a working media. Firstly arriving from an external source water enters the cooling jackets of the cathode and the cylindrical anode, where it is preheated to high temperatures. In extreme cases. Water can be heated till the boiling point. Then, this water is supplied to the plasmatron where it is sprayed as the media for the plasma generation. A special twist of the water flow protects the anode walls from overheating.

1. Despite the increasing oil production in the world, we must remember that the oil reserves on Earth are limited. Soon these reserves will be exhausted. At the same time, subsoils contain enormous reserves of hardly extractable heavy oil and natural bitumen. Therefore, the search of new innovative technologies for the extraction, transportation and processing of heavy oil and natural bitumen becomes very topical. Recently the plasma-chemical methods of heavy hydrocarbons processing [1-10] become very popular due to its high efficiency and simplicity.

The Republic of Tatarstan is well-known for its large reserves of natural bitumen and high-viscosity oil, which are very promising sources for oil production. Located at depths of 50-400 m., heavy oil and bitumen have high viscosity and high coking ability. It leads to problems during the extraction, transportation, and processing of raw materials. Nowadays, a lot of research aimed to find economically and technologically effective, as well as environmentally friendly ways for extraction and processing of natural bitumen.

One of the promising extraction ways is heating of the layers of high viscosity oil and bitumen with overheated water vapor. However, water steam prepared on the surface causes thermal and power losses as a result of the environment heating and the transportation. Therefore, the economic efficiency of this method come into question.

In this work, we propose a unique submersible arc vapourtron. It is designed to generate large amount of overheated to a high temperature water vapor close to the application area. The most prospective application of such vapourtron is producing and processing of heavy oil and natural bitumen. Vapourtron represents an electric-arc plasmatron using water or water vapour as a working media on the figure.
First, water from an external source is supplied to the cooling jacket of the cathode 1 and the cylindrical anode 5 through the electromagnetic valve 8. Second, it is heated to high temperatures. In extreme cases, water can even reach state of boiling. Then, this water is supplied to the plasmatron where it is sprayed as the media for the plasma generation. A special twist of the water flow protects the walls of the anode from overheating.

The experimental setup consists of an electric power supply, an arc ignition, a water cooling, a water supply, an electric arc vapourtron, a pump for water supplying, a pressure pipe, an output pipe, and a pump for raw materials evacuation. The body of the vapourtron is made of brass, which is corrosion resistant. The vapourtron consists of a water-cooled cylindrical anode 5, a tungsten (zirconium, graphite) cathode 2. The solenoid valve 8 is used to regulate the water supply.

Compact plasmatron should be placed on the bottom of the inlet water pipe, whereas the outer surface of the electrodes is covered by a dielectric material.

Water is pumped down by inlet water pipe. Isolated electric wires run down through the same pipe to the electrodes. An electric arc is generated by applying high voltage pulse. After the arc ignition the solenoid valve opens the water supply to vapourtron. Electric arc discharge is carried out in water vapour. Water vapor twisting stabilizes the arc and protects the inner walls of the anode from overheating.

By the action of superheated vapour, the layer gradually becomes heated, the viscosity of raw materials will decrease. Vapour temperature in the plasma core of vapourtron reaches several thousand degrees. Near the oily layer, the vapour temperature will reach several hundreds of degrees, leading therefore to a thermal cracking of bitumen. Light hydrocarbons will be formed from the excess hydrogen, while additional heat will be emitted within the layer due to the excess of free oxygen. Fortunately, both effects are desirable.

Preheated and pre-processed raw materials will be pumped up with the help of a special pump and piped in the tank.

Long-term processing significantly decreases the viscosity of bitumen and therefore facilitates its transportation.

We estimated the cost of 1 kg of water vapor, based on the heat balance equation:

$$ IUt = c_1 m_1 \Delta T_1 + c_2 m_2 \Delta T_2 + \lambda m_2 + k_1 \mu n_1 $$

(1)
where: $I$, $U$ – the total current and the discharge voltage, $c_1, m_1$ – heat capacity and mass of heated water, $c_2, m_2$–heat capacity and mass of the formed vapour, $\Delta T_1$– the increment of water temperature, $\Delta T_2$– increment of the steam temperature; $\lambda$ is the specific heat of vaporization; $\mu$ – the specific heat of dissociation of water molecules; $m_3$ - the mass of dissociated water molecules, and $k$ – the degree of dissociation of water vapor.

Table 1 summarizes the experimental data taken to estimate the assessed results.

| Current $I$(A) | 250 |
|----------------|-----|
| Voltage $U$(V) | 200 |
| Time of experiment $t$(s) | 180 |
| Temperature increment $\Delta T$(K) | 600 |

Let’s assume the following constants:

water heat capacity – $c_1= 4187 \frac{J}{kg \cdot K}$, water vapour heat capacity – $c_2= 2020 \frac{J}{kg \cdot K}$, $\lambda = 2.26 \times 10^6 \frac{J}{kg}$, $\mu = 52 \times 10^6 \frac{J}{kg}$.

Then the mass rate of water to steam conversion, without taking into account the dissociation of water molecules, can be presented in the form:

$$
\frac{m}{t} = \frac{U \cdot J}{c_1 \Delta T_1 + c_2 \Delta T_2 + \lambda + \mu} = \frac{200 \cdot 250}{4187 \cdot 80 + 2020 \cdot 600 + 2260 \cdot 10^3} = 0.015 \frac{kg}{s}
$$

that corresponds to about 50 kg/hour. On the basis of the received values, to produce 1 kilogram of steam at 600C, the experimental setup will consume 1 kW h of the electric energy.

It should be also considered, that about 10% of water molecules will disassociate to an atomic state ($k = 0.1$), then

$$
\frac{m}{t} = \frac{U \cdot J}{c_1 \Delta T_1 + c_2 \Delta T_2 + \lambda + \mu} = \frac{200 \cdot 250}{4187 \cdot 80 + 2020 \cdot 300 + 2260 \cdot 10^3 + 0.1 \cdot 520 \cdot 10^3} = 0.006 \frac{kg}{s}
$$

Then, to produce 1 kilogram of steam at 600C the experimental setup will require about 2 kW h of the electric energy.

To conclude, the proposed experimental setup has heat use efficiency close to 100 percent as it can produce overheated water vapour directly inside the oily layer. Therefore, the vapourtron can undoubtly be used to generate vapour directly inside the oily layer.

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