Developing a New Type of Jointing the Metal Plates of a Heat Exchanger

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Abstract. This paper proposes using a new composition of the metal polymer compound to joint heat exchanger plates. This composition makes it possible to improve the factors of plate junction, such as the cost, safety, efficiency, and rate of the junction procedure. We consider the benefits and drawbacks of the two main ways to joint metal plates of brazed steel plate heat exchangers (BPHE), namely, copper brazing and laser beam welding; propose to joint plates using a metal polymer compound consisting of the metal powder of steel 316L and binding agents; show the metal polymer compound production process; provide the results of the component mixing process depending on the parameters, such as duration and rate of mixing; as well as present the resulting density of the specimens made of the metal polymer compound, depending on the mixing conditions.

Keywords: Plate heat exchangers, metal-polymer composite, copper brazing, laser beam welding

1. Introduction
Plate heat exchangers (PHE) are currently one of the most promising devices in the modern chemical, oil refining, engineering, and other industries. The main PHE application (about 50%) is their use in heat supply (heating and hot water supply systems) cooling systems [1, 2].

The most demanded and promising heat exchangers are the brazed steel plate ones (BPHE) [3, 4]. Due to their design and ease of manufacturing, BPHEs are much cheaper, more efficient and reliable than shell and tube or knock-down PHEs. Figure 1 shows the appearance of a brazed heat-exchange apparatus.

Figure 1. Brazed heat-exchange apparatus
BPHEs should comply with the following requirements:
- transfer the required amount of heat from one medium to another with the required end temperatures at the best possible heat exchange capacity;
- have a heat exchange surface area and other design elements of the apparatus exposed to the working fluid that are sufficiently resilient to heat conductor exposure;
- work reliably at the given thermodynamic parameters of the working media (pressure, temperature, flow) and various physical state;
- allow for regular cleaning of the heat exchange surfaces and ensure their maintainability in order to preserve continuous serviceability when operated with media that cause deposition on the heat exchanger walls;
- be durable enough to ensure safe condition at tensions that occur as a result of the working medium pressure as well as due to thermally-induced displacements of various parts of the heat exchanger.

In order to ensure the given technical requirements at the stage of BPHE design and development, one should pay particular attention to the technology of plate junction into a heat exchange matrix, as well as the brazing alloy material.

Currently, there are two types of metal BPHE plate junction: copper brazing and laser beam welding. Copper brazing is an efficient and cost-effective way to produce plate heat exchangers (Figure 2) [5]. This method uses a copper plate as the junction material to joint stainless-steel plates with each other. This technological process for plate junction is performed in a vacuum furnace in inert gas atmosphere. The brazing process should be closely controlled as copper can penetrate stainless steel causing metal embrittlement while it is liquid, affecting the strength of the manufactured product. Sometimes, it turns out to be difficult to apply or even determine the most suitable welding filler. Also, when this BPHE is used, copper particles can penetrate the working medium, which is not allowed in certain cases.

In laser beam welding, corrugated stainless steel plates are positioned opposite one another and the material at the contact points is melted with laser (Figure 3) [6]. As steel hardens, metal diffusion occurs on the surfaces of the plates. This method has several drawbacks. Sometimes, it is necessary to adapt the product design to the limitations of this welding technology. In addition, this manufacturing method is expensive. The process must take place in a chemically inert environment, otherwise materials react with oxygen contained in the air, worsening the quality of weld seams. The equipment required for such welding is also quite expensive.
When choosing a particular jointing method, one should consider many factors, such as cost, safety, productivity, and rate of the plate jointing process. The above methods of BPHE plate junction have certain advantages, but there is still a need for new junction methods that will improve these factors [7, 8, 9].

The purpose of the article is to develop a composition of metal-polymer composites for BPHE plate junction.

2. Source data

The metal-polymer composite consists of metal powder and a polymer binder. To develop the composition of metal-polymer composites, we chose steel 316L as the main powder. The chemical composition of the powder is shown in Table 1 [10].

| C % | Cr % | Ni % | Mn % | Mo % | Si % | Fe % |
|-----|------|------|------|------|------|------|
| ≥ 0.03 | 15–17 | 14–16 | ≤ 0.8 | 2.5–3 | ≤ 0.6 | Balance |

The characteristics of the selected powder mixture’s particle are provided below:

- **Bulk density**: 7.6 g/cm³
- **Grain size analysis (Figure 4)**: D10 — 27 μm, D50 — 38 μm, D90 — 57 μm

The binder system consists of three components:

- a) the main component of the binder;
- b) the auxiliary binder;
- c) the multifunctional surfactant.

Paraffin oil wax YaV-1 was chosen as the main binder. Low density polyethylene (LDPE) was used as the auxiliary binder to prevent the metal-polymer composite from spreading over the plate during the sintering process. Stearic acid (and its derivatives) was selected as the immediately available and most suitable surfactant additive for the following reasons:

1) hydrophobically compatible with the wax binder;
2) decreases metal-polymer composite viscosity;
3) removed by distillation;
4) removed without carbon residues.
There are many publications, in which [11, 12, 13] the information on choosing the optimal ratio of metal powder and binder in a metal-polymer composite is provided. All the researchers give approximately the same powder-to-binder ratio at the level of 60% to 40% by volume [14]. In terms of the weight, this ratio gives about 90% or more powder in the metal-polymer composite. When manufacturing the metal-polymer composite, we mixed the binder and powder components with a laboratory twin-screw mixer (see Figure 5).

![Figure 5. Laboratory twin-screw mixer](image)

After the components have been mixed, the finished composite is poured from the mixer onto a special metal rig and then solidifies (Figure 6).

![Figure 6. Metal-polymer composite](image)

3. The experiment results. Discussion
Mixing the metal-polymer composite components is an important step, which determines its homogeneity and the quality of the final junction of the plates. Deficiencies in the metal-polymer composite quality cannot be rectified at the subsequent stages of PHE plate junction (debinding and high-temperature sintering). Failure to uniformly distribute the metal powder in the metal-polymer composite inevitably leads to defects in the final product.

The following parameters have an impact on the final properties of the metal-polymer composite: mixing rate and duration, design and geometry of the mixer blades, mixing temperature, particle size distribution of the metal powder, viscosity.

The mixing process was carried out for 30 to 50 minutes at 10 to 30 rpm. At the first stage, we loaded powder and paraffin, and then the remaining fractions of the binder. The maximum percentage of powder loading was 63.5% of the volume (maximum torque). See Table 2.
### Table 2. Mixing parameters.

| Sample | Powder Infeed (%) | Mixing rate (rpm) | Mixing temp (°C) |
|--------|-------------------|-------------------|------------------|
| 1      | 61%               | 10                | 130              |
| 2      | 61%               | 10                | 150              |
| 3      | 61%               | 30                | 130              |
| 4      | 61%               | 30                | 150              |

The torque of the mixing process at different rates and temperatures changes during the mixing process, and the metal-polymer composite becomes homogeneous at the final stage, while the torque remains the same for each sample. Increasing the mixing rate from 10 to 30 rpm reduces the mixing time required to achieve uniformity at a temperature of 130 °C. When mixing at a temperature of 150 °C, the time needed to achieve homogeneity of the metal-polymer composite reduced even more. In addition, increasing the mixing temperature reduced the time needed to achieve homogeneity. The amount of energy supplied, which was transferred through the mixer blades to the mixing process, increases as the rate grows.

### Table 3. Raw material density.

| Sample | Density, g/cm³ |
|--------|----------------|
| 1      | 5.01 ± 0.02    |
| 2      | 5.05 ± 0.02    |
| 3      | 5.12 ± 0.02    |
| 4      | 5.19 ± 0.02    |

We measured the density of the obtained metal-polymer composite and the raw material homogeneity. Table 3 shows that each sample has a small standard deviation and that the material achieved homogeneity. At a mixing temperature of 150 °C, an increase in mixing rate leads to a higher density of the metal-polymer composite. However, the density remains stable at a mixing temperature of 130 °C. Specimen 4 has the highest density, which is due to the combined increase in the mixing rate and temperature as a result of the viscosity effect of polyethylene, which has a melting point of 125 °C. Polyethylene viscosity decreased at higher temperatures, which contributed to good mixing quality.

Agglomeration of powder particles is a common phenomenon for nanometer-sized powders. For this reason, the share of nanoscale particles should not exceed 1% of the total volume. Agglomeration generally decreases as the mixing rate and temperature increase. It can be concluded that an increase in the mixing rate has a significant effect on the final quality of the metal-polymer composite. However, a high mixing rate leads to penetration of air into the metal-polymer composite. In turn, increasing the mixing temperature reduces the metal-polymer mixture viscosity, which facilitates the process of achieving homogeneity of the metal-polymer composite.

### 4. Conclusion

The objective of the research was to analyze the effect of mixing time, rate, and temperature on the density and homogeneity of the 316L metal-polymer composite. The experimental results showed that increasing the rate and temperature of mixing the components of the metal-polymer composite, as a rule, reduces the mixing time required to achieve homogeneity of the metal-polymer composite. In addition, an analysis of the metal-polymer composite density showed that the rate of 30 rpm and the temperature of 150 °C ensure the optimal mixing time and maximum density.

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