Experimental investigations [1, 2] have demonstrated that the normal type of agitator (propeller, blade, or turbine) is not effective for mixing viscous (>100 poise) liquids. This is due to the fact that the mixed volume of viscous liquids is limited to the area swept by the body of the agitator. This area is limited in the above-mentioned types of agitators. Low heat-transfer rates result from this poor quality of mixing.

We carried out a comparative investigation of three agitator designs: frame (tubular) conical-cylindrical, and spiral ribbon. All these agitators sweep a large part of the vessel volume while the first two also act as heat-transfer surfaces.

The two side blades of the tubular frame agitator (Fig. 1a) are heat-transfer elements (arrows indicate the inlet and outlet of the cooling liquid) with a total area of 0.055 m².

The heat-transfer elements of the conical-cylindrical agitator* (Fig. 1b) are the outer cylindrical surface (0.186 m²) and the inner truncated cone surface (0.112 m²) (the end surfaces were insulated during the experiments). The effectiveness of each surface element was investigated separately. Cooling water entered the body of the agitator through a hollow shaft and exited through the upper opening in the shaft.


Fig. 1. Schematics of the agitators: a) tubular frame agitator; b) conical-cylindrical agitator; c) two flight spiral ribbon agitator.
Fig. 2. The amount of heat generated by dissipation of mechanical energy $Q_V$ and effective heat removal in the vessel volume $Q_{eff}$ as a function of agitator rotational speed operating in a 120 poise liquid: $Q_{eff} = f(n)$; $Q_V = f(n)$; 1) tubular frame agitator; 2) conical-cylindrical agitator; 3) two flight spiral ribbon agitator; 4) single flight spiral ribbon agitator.

Fig. 3. Effective heat transfer coefficient $a_{eff}$ as a function of agitator rotational speed $n$ with a 120 poise liquid. Nomenclature is the same as in Fig. 2.

Figure 1c shows the construction of a two flight spiral ribbon agitator (heat-transfer surface of the vessel jacket was 0.306 m²). A single flight spiral ribbon agitator, with identical dimensions, was tested for comparison.

The agitators were tested in a 30 liter vessel by mixing polymethylsiloxane liquid (120–200 poise) and polyglycerine (20–200 poise). The following data was collected during the tests: heat removed for cooling the viscous liquid, heat-transfer coefficient from the liquid to the vessel wall (or to the agitator surface), temperature distribution in the vessel, and power consumption for mixing.

The amount of heat removed by the cooling medium $Q_{rem}$ during mixing of a viscous liquid is comparable to the heat $Q_V$ absorbed by the liquid as a result of dissipation of mechanical energy which depends, other conditions being equal, on the agitator's rotational speed. The effective heat removal $Q_{eff}$ in the vessel is expressed by the equation

$$Q_{eff} = Q_{rem} - Q_V.$$  

The effective heat removed depends on the agitator's rotational speed and typically has a maximum at a certain agitator speed (Fig. 2). Maximum $Q_{eff}$ is displaced to lower speeds for more viscous liquids.

The function $Q_{eff} = f(n)$ is shown in Fig. 2 for single flight spiral ribbon, two flight spiral ribbon, frame, and conical-cylindrical agitators with a 120 poise liquid. The amount of heat removed by the first three types was roughly equal, while the fourth removed 25–30% less heat when only the outer cylindrical surface was used for cooling (the inner surface was insulated). Maximum effective heat removal is achieved by the single flight spiral ribbon agitator, while the conical-cylindrical agitator is the least effective. The maximum values of $Q_{eff}$ for the frame and two flight spiral ribbon agitators are very close to each other while the curves of $Q_{eff} = f(n)$ for ribbon agitators are flatter so that they can be used effectively over a wider range of agitator speeds.

The greatest amount of heat from mechanical energy dissipation is produced by the tubular agitator, particularly at speeds in excess of 50 rpm.

The effective heat-transfer coefficient $a_{eff}$ was determined from the average operating temperature difference $\Delta t$ and the heat-transfer surface $F$:

$$a_{eff} = \frac{Q_{eff}}{\Delta t F}.$$