# TYPE 745: VARIABLE SPEED PUMP, MASS FLOW RATE CALCULATED FROM AVAILABLE POWER, POWER DRAWN CALCULATED FROM MOTOR EFFICIENCY AND PRESSURE RISE

## General Description

Type745 models a pump that sets its outlet mass flow rate based upon user specified available power. It calculates the power drawn by the pump based on motor efficiency overall pump efficiency, and pump pressure rise. Like most pumps and fans in TRNSYS, Type745 takes the inlet mass flow rate of fluid as an input but does not necessarily pass the value through to its output. Type745 sets the downstream flow. Because of the power input, this pump model is particularly useful for direct drive applications in which a pump is directly connected to an intermittent power source.

## Nomenclature

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| $\dot{m}$ | [kg/hr] | Mass flow rate of fluid passing though the pump. |
| $\dot{P}_{available}$ | [kJ/hr] | Power available to drive the pump. |
| $\dot{P}$ | [kJ/hr] | Power actually drawn by the pump. |
| $\dot{P}_{shaft}$ | [kJ/hr] | Shaft power required by the pumping process (does not include motor inefficiency) |
| $\dot{W}_{pumping}$ | [kJ/hr] | Shaft work performed in the pumping process (does not include motor or pumping inefficiency). This value is also called the ideal work performed. |
| $\rho_{fluid}$ | [kg/m$^3$] | Density of fluid flowing through the pump. |
| $\Delta p$ | [ - ] | Pressure rise across the pump. |
| $\eta_{motor}$ | [0..1] | Efficiency of the pump motor |
| $\eta_{overall}$ | [0..1] | Overall pump efficiency (motor efficiency * pumping efficiency) |
| $\eta_{pumping}$ | [0..1] | Efficiency of pumping the fluid |
| $\dot{Q}_{fluid}$ | [kJ/hr] | Energy transferred from the pump motor to the fluid stream passing through the pump. |
| $f_{motorloss}$ | [0..1] | Fraction of pump motor inefficiencies that contribute to a temperature rise in the fluid stream passing through the pump. The remainder of these inefficiencies contribute to an ambient temperature rise. |
| $\dot{Q}_{ambient}$ | [kJ/hr] | Energy transferred from the pump motor to the ambient air surrounding the pump. |
| $T_{fluid,out}$ | [kJ/kg] | Temperature of fluid exiting the pump |
| $T_{fluid,in}$ | [kJ/kg] | Temperature of fluid entering the pump |

## Detailed Description

Type745 has three modes of operation that depend upon the input values at a given time. If the user supplied power is below the minimum allowable power for the pump to operate then the fluid outlet temperature is set to the fluid inlet temperature. Outlet mass flow rate, power drawn by the pump, energy transferred to the fluid stream and energy transferred to the pump surroundings are set to zero.

In the second mode of operation, the pump pressure rise has been set to zero. In this case the pump is allowed to operate but a calculation of power draw (and consequently calculation of the various energy transfers) is not possible. Under a zero pressure rise condition, the pump mass flow rate is set to the

rated value (supplied as a parameter) while the power drawn by the pump, energy transferred to the fluid stream and energy transferred to the pump surroundings are set to zero. While physically unrealistic, this condition allows Type745 to be used in direct connect simulations in which a pump may be driven by an intermittent power source and in which minimum allowable power for the pump to operate is known but other pump characteristics are unknown.

In the third mode of operation, power above the minimum allowable level and a valid pressure rise have been specified at the current time step. The pump is considered to be ON and operating at an efficiency specified by the user. Since the user is asked to specify both overall pump efficiency and motor efficiency, the efficiency of the pumping process itself is calculated as

$$\eta_{pumping} = \frac{\eta_{overall}}{\eta_{motor}} \qquad \text{(Eq. 745.1)}$$

If it is not specifically listed in available data, the overall efficiency of the pump may be calculated from nameplate values using a consistent set of units as:

$$\eta_{overall} = \frac{\dot{v}_{rated}\ \Delta p_{rated}}{\dot{P}_{rated}} \qquad \text{(Eq. 745.2)}$$

The pump is producing a fluid outlet flow given by equation 745.3.

$$\dot{m} = \frac{\dot{P}_{available}\ \rho_{fluid}\ \eta_{motor}\ \eta_{pumping}}{\Delta p} \qquad \text{(Eq. 745.3)}$$

If the power delivered to the pump results in a flow rate greater than the pump rated flow, the excess power is assumed to be safely dumped by the pump. The mass flow rate is limited to its maximum allowable value. The power actually drawn by the pump is calculated according to equation 745.4, which is simply a rewriting of equation 745.3.

$$\dot{P} = \frac{\Delta p\ \dot{m}}{\rho_{fluid}\ \eta_{motor}\ \eta_{pumping}} \qquad \text{(Eq. 745.4)}$$

The power required at the shaft (neglecting motor loss effects) is

$$\dot{P}_{shaft} = \dot{P}\ \eta_{motor} \qquad \text{(Eq. 745.5)}$$

Energy transferred from the pump motor to the fluid stream is calculated as shown in equation 745.6

$$\dot{Q}_{fluid} = \dot{P}_{shaft}\left(1-\eta_{pumping}\right)+\left(\dot{P}-\dot{P}_{shaft}\right)f_{motorloss} \qquad \text{(Eq. 745.6)}$$

In which $\eta_{pumping}$ is the pumping process efficiency and $f_{motorloss}$ is a value between 0 and 1 that determines whether the pump motor inefficiencies cause a temperature rise in the fluid stream that passes through the pump or whether they cause a temperature rise in the ambient air surrounding the pump. Through use of the $f_{motorloss}$ fraction, the user can in effect specify whether the pump has an inline motor, in which case all waste heat would impact the fluid stream temperature and $f_{motorloss}$ would have a

value of 1, or whether the pump motor is housed outside of the fluid stream such that it's waste heat impacts the ambient and $f_{\text{motorloss}}$ would have a value of 0.

The energy transferred from the pump motor to the ambient is given by equation 745.7.

$$\dot{Q}_{ambient} = \left(\dot{P} - \dot{P}_{shaft}\right)\left(1 - f_{motorloss}\right) \quad \text{(Eq. 745.7)}$$

The temperature of fluid exiting the pump can now be calculated as shown in equation 745.8.

$$T_{fluid,out} = T_{fluid,in} + \frac{\dot{Q}_{fluid}}{\dot{m}} \quad \text{(Eq. 745.8)}$$

Type745 does not model pump starting and stopping characteristics; as soon as the pump input power changes, the outlet flow of fluid jumps to match the input power. The time constants with which pumps react to input changes are much shorter than the typical time steps used in hydronic simulations.