it may be possible to cause the cavity to collapse in the fluid instead of against the structure.

Conclusions

Almost all of the inducers tested have had the inlet area obstructed by 10 or 15 per cent by the impeller blades. The effect on performance resulting from impellers with fixed values of inlet-area obstruction and with one or more blades has not been completely evaluated. Neither has the effect on performance been completely determined resulting from varying the number of blades with the same value of solidity. The range of solidities tested has been from 2.5 to 3.5, with the ratio of length of inducer to diameter varying from 0.4 to 0.6. No optimization with respect to the foregoing parameters has been performed.

There is definite evidence that an outside shroud reduces the maximum suction specific speed obtainable from inducers. Apparently the flow over the impeller tips tends to unload the blades in the region of most severe cavitation. This also suggests the possibility that holes or slots in the blades in cavitation areas may permit blade unloading or even provide a fluid cushion against the blade surface against which the cavitation bubbles may collapse.

Scale factors of 2 or 3 do not materially affect over-all performance in the range tested, but for much larger scale differences, performance may be affected by the actual time required for the formation and collapse of the cavity.

The head developed by the inducer or impeller at each section definitely affects performance, since rapid turns, etc., can cause low local pressures and possible separation.

Discussion

F. C. Gilman.[6] The authors and their company are to be commended for making available to the pump industry as much as they have of this significant piece of pioneer work. Applications for high-suction specific-speed pumps which operate beyond the range of incipient cavitation are rapidly increasing with the variety of liquids being pumped. A few parts of the paper seem to need clarification, however.

In the introduction, it is suggested that improvements in suction characteristics are desirable for applications in which liquids with high boiling points are pumped. Is not the significant feature of the type of application that the suction pressure does not exceed the vapor pressure by a wide margin? Boiling point by itself has little significance.

The jet pump is mentioned as a means of increasing suction specific speed. Jet pumps which use a portion of the pumped liquid to increase impeller-suction pressure have a definite place where suction pressure as such needs to be boosted. This is usually in a low specific-speed range. Where high-suction specific speed is desired to achieve high specific speed, this method soon encounters the law of diminishing returns since the impeller must handle not only the quantity required externally but also a significant additional quantity for recirculation.

Under the subject of inlet conditions, the authors state that in an impeller designed to operate with cavitation the passage areas must be increased to accommodate the lower density saturated vapor. This gives the impression that the vapor demands space as would a noncondensable gas. With some liquids this actually may be so, especially if Stahl and Stepanoff[7] are correct in their claim that heat-transfer limitations control the rate of vapor evolution and collapse. When pumping liquids like cold water the vapor merely fills up the space avoided by the moving liquid. If we provide extra area in the passages it is because either we do not know just how the liquid is going to move or we know that under varying capacity the liquid will fill different paths and we try to provide for variation within the fixed geometry.

Equation [2] needs some correction as it appeared in the preprint. On the right side of the denominator of Equation [2] the factor $(1+k)/k_a^2$ should be replaced by $(k + k_a)$ if k_a is defined as in the preprint by

$$\Delta h_1 = \frac{k_a V_a^2}{2g}$$

Equations [3] and [4] are also inconsistent with this definition of k_a.

The writer would urge the avoidance of the term "shockless" to indicate zero angle of incidence in turbomachines. The term shock should be reserved for the phenomenon of velocity and pressure discontinuity associated with supersonic flow.

The authors suggest that prerotation may be the reason why they find a slightly larger entrance-vane angle required than would correspond to zero incidence based on the approach axial velocity. It is the writer's view that unless the angle is increased to compensate for the area occupied by the vane, not only will an axial acceleration be required, but the same precentage increase will be needed in the much higher relative velocity.

The single-vane inducer form described in this paper results in minimum blockage for a given minimum vane thickness. It also provides a long passage in relation to cross section which is helpful for consolidating the liquid within the limits of the inducer. The length-over-width ratio at the root-mean-square radius appears to be about 50 which seems excessive from considerations of best efficiency. If actual cavitation can be tolerated without prohibitive damage, then one of the forms of impeller suggested by Dr. Wislicenus[8] would seem to offer an opportunity for a significant forward step in this field.

Authors' Closure

The authors appreciate the comments of Mr. F. C. Gilman. We are in agreement on the comments made relative to the jet pump.

The increase in inlet size, we feel, is required because the mean specific volume of the fluid increases as the intensity of the cavitation increases. The increase in specific volume may be considered to result from pure separation or vaporization. The vaporization may occur at a constant temperature (heat from external source being required) or expansion isoenthalpically beyond the saturated liquid line with no addition of heat being required. In either case, the velocity of the fluid is limited by the available ΔH to vapor pressure, but since the specific volume increased due to separation or vapor expansion, it follows that the area required to pass the flow must increase.

Tests were performed (with cold water) that confirmed the need for added area. Test data also showed (within experimental error) that the pressure in some areas dropped below vapor pressure. This factor would imply that the inlet area increase requirements be a function also of the properties of the fluid.

The Δh_1 term as defined in the preprint of this paper was not used in the derivation of Equation [2]. The analysis was based on Δh_1 and k_a as defined in the present text. The factor $(1 + k)/k_a^2$ in Equation [2] is therefore correct. However, Equations [2] and [3] as stated in the preprint were incorrect due to a typographical error. The typographical error consisted of the omis-

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[7] "Thermodynamic Aspects of Cavitation in Centrifugal Pumps," by H. A. Stahl and A. J. Stepanoff, published in this issue, pp. 1691–1693.

[8] "Critical Considerations on Cavitation Limits of Centrifugal and Axial Flow Pumps," by G. F. Wislicenus, published in this issue, pp. 1707–1714.

sion of required brackets which have been incorporated in the present text.

The slightly larger entrance vane angle can be explained in part by the area occupied by the impeller vane, but over and above this, an increase in entrance vane angle was noted to be necessary. Test data have shown that the highest suction specific speed for a given design was obtained for a lower value of flow than that required for zero angle of incidence, vane obstruction being considered.

It is true that the composite impeller with long passage length is lower in efficiency for the design specific speed than one designed with a shorter passage length; however, it was not possible to make the shorter impeller operate at as high a value of suction specific speed. It has also been observed that the short-vaned impeller received severe cavitation damage in a matter of minutes due to the more rapid turning, whereas many hours of operation have been attained with an impeller that has long passage with no visible cavitation damage.