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PUMP CAVITATION AND INDUCER DESIGN

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1. INTRODUCTION

Details of past work on sodium pump development- and cavitation studies executed mainly for SNR 300 were reported earlier, /1-8/. On the occasion of previous DeBeNe-CEA meetings on cavitation and inducer-type pumps for the follow-up line the Dutch work on the subject was reported, /9-10/. The experimental programme for the inducer design was carried out by Neratoom in close cooperation with FDO in the period 1979-1981.

Among the requirements for large sodium pumps are long life (200000 hours up to 300000 hours) and small size of impeller and pump, fully meeting the process and design criteria. These criteria are the required "Q, H, η characteristics" in combination with a low NPSH-A value and the avoidance of cavitation damage to the pump. The pump designer has to develop a sound hydraulic combination consisting of suction arrangement, impeller design and diffuser. On the other hand the designer is free to choose an optimal pump speed (n). The pump speed in its turn influences the rotordynamic pump design and the pump drive.

The introduction of the inducer as an integral part of the pump design is based on following advantages:

- no tip cavitation;
- (possible) cavitation bubbles move to the open centre due to centrifugal forces on the fluid;
- the head of the inducer improves the inlet conditions of the impeller

The aim of an inducer is the increase in the suction specific speed (S_A value) of a pump whereby the inducer functions as a pressure source improving the impeller inlet conditions. With inducer-impeller combinations values up to S_A = 15000 are realistic. With the use of an inducer the overall pump sizes can be reduced with ca. 30 %. Pumps commonly available have S_A values up to a maximum of ca. 10000.

A development programme was executed for SNR 300 in order to reach an increase of the suction specific speed of the impeller from S_A 8200 to S_A 11000.

Further studies to optimize pumps design for the follow up line introduced the "inducer acting as a pre-impeller" development. This programme was executed in the period 1979-1981. At the FDO premises a scale 1 : 2.8 inducer impeller combination with a suction specific speed S_A = 15000 was developed, constructed and tested at the water test rig. This water test rig is equipped with a perspex pipe allowing also visualisation of the process. Applying high speed film techniques in combination with a stroboscope the cavitational behaviour of the pump can be analysed outside of the loop.

Earlier studies on the cavitation behaviour of impellers in water and in liquid sodium proved that water can be used as a representative test fluid for sodium.

The development of sodium pumps is sponsored by the Dutch Government and executed within the framework of an international cooperation agreement for the research, development and construction of breeder reactor plants.

2. SNR-300 POWER PLANT

The SNR 300 is a loop type liquid metal fast breeder reactor with three primary and three secondary loops. Two of the secondary loops are equipped with straight tube steam generators, the third loop is equipped with helical tube steam generators. The primary pumps are situated in the hot leg of the primary loops, the secondary pumps in the cold leg of the secondary loops. See for details /5-8/.

3. SODIUM PUMP DEVELOPMENT FOR SNR-300

The design characteristics of the primary SNR-300 pumps are dictated by the system requirements. The sodium in the reactor is covered by an inert gas (argon) in order to separate the sodium from the roof structure of the reactor. The three primary pumps have a vertical arrangement with argon above the free sodium surface. The reactor and the three primary pumps are connected by the special suction piping, a 180 degree bend, being a major demand due to restrictions of the available net positive suction head (NPSH), and the sodium overflow connection and the argon connection in order to equalize the pressure in these communicating vessels. In the space above the hot sodium (546°C), which is filled with argon, the temperature can be reduced considerably by thermal shields; this is necessary for the shaft seal (80°C).

The sodium pump development in the Netherlands started with a small pump (280 m^3/h) with radial suction and central discharge. Next step was the design, construction and prototype test of a 5000 m^3/h pump at the APB loop at Interatom (Bensberg FRG) see /1-4/.

This development step consisted of a design phase, the construction (by Stork Boilers), the watertests, sodiumtests and an evaluation phase. The prototype pump was tested for 6000 hours in the Interatom sodium pump test loop at temperatures between 200°C and 580°C. The results were reported extensively /1-4/.

Sodium testing confirmed that the hydraulic performance of impeller pumps in sodium can be predicted from model and fullsize tests in water. The importance of the pump inlet conditions became obvious /5-6/. A special 180 degree bend at the inlet of the primary pump was necessary to realize an acceptable uniform velocity destribution at the pump inlet, since no strainers were acceptable in the system and no straight length could be accommodated, see /7/.

The high operating temperatures and the fact that sodium aggravates the effect of thermal shocks, asked for special solutions. The pump was designed to avoid thermal stresses. For that reason the internals are connected to the pump-vessel at the upper part only. Piston rings are placed in the lower part between the vessel and the internals in order to reduce the internal leakage of the pump. The shaft is supported by a roller-bearing at the top and a hydrostatic sodium-bearing in the lower part, fed by the pump discharge. Design and hardfacing of this sodium-bearing proved to be excellent during the testing of the prototype pump. Visco-seals have been developed, designed and tested for use in all of the six SNR-300 pumps. The three primary and three secondary sodium pumps have one-stage, single suction, radial flow impellers, fixed to hollow shafts. The SNR-300 pumps were designed and constructed by using the experience obtained with the prototype pumps.

4. SODIUM PUMP DEVELOPMENT FOR THE FOLLOW-UP-LINE

The system requirements for sodium pumps for larger power plants are moving towards capacities of about 20000 m^3/h with low NPSH-A.

The aim for compact high speed impellers for pumps operating under poor suction conditions led to the need for higher suction specific speeds. An increase in suction specific speed to an S_A of 11000 was realised by the development of the SNR-300 primary pump impeller out of that of the prototype pump. With this improved impeller design, however, the limit of manufacturing possibilities was reached. For the next generation reactor it was therefore necessary to develop an impeller or an inducer/impeller combination with a further increased suction specific speed. With an inducer/impeller combination a long lifetime and easy manufacturing methods could be obtained. The influence of the suction specific speed on the dimensions of impeller and pump concept has been analysed.

For the system requirements of the primary pumps for the next generation reactor (capacity 5.47 m^3/s, head 120 m (loop type) versus 70 to 91 m (pool type), NPSH-A = 12 m) the influence of the suction specific speed on the outlet diameter of the impeller (and pump) is very clear, see relevant diagram. An impeller with a suction specific speed of S_A = 11000 leads to an impeller with a diameter of ca. 1,70 m and 1,25 m for an inducer/impeller combination with an S_A value of 15000.

In order to have good suction head conditions for the impeller an inducer is used as a pre-impeller. The inducer picks up the fluid, prerotates it and supplies a low head for the actual impeller. Thanks to its special shape the inducer can operate at a lower NPSH value than a conventional impeller. The inducer-impeller combination operates at a higher speed matching the NPSH demand. The result of this is a small sized impeller and thus pump.

5. INDUCER DESIGN PHILOSOPHY.

For the design of pumps with favourable cavitation behaviour use is made of the inlet geometry optimisation derived from /10/. Cavitation inception is assumed to occur at the leading edge of the blade near the front shroud.

The net positive suction head at this point is given by the following equation:

$$NPSH = \sigma_b \frac{w_{1s}}{2g} + \frac{c_{1s}}{2g} \qquad (1)$$

The optimum values of the blade inlet angle β_{1s} and the inlet flow coefficient $\emptyset_1$ can be determined if the blade cavitation factor σ_b, the blockage coefficient q_{1s}, the hub/shroud diameter ratio λ and the meridional velocity ratio c_r are known.

$$\sigma_b = \frac{p_1 - p_v}{\frac{1}{2} \rho w^2_{1s}} = \text{blade cavitation factor} \qquad (2)$$

$$q_{1s} = 1 - \frac{z \; t_{1s}}{\pi D_{1s} \sin \beta_{1s}} \qquad (3)$$

= blade blockage coefficient at the leading edge near the shroud

$$\lambda = \frac{D_{oh}}{D_{1s}} \qquad (4)$$

$$c_r = \frac{c_{m_{1s}}}{c_{m_1}} \qquad (5)$$

β_{1s} = inlet blade angle at shroud

p_1 = static pressure at inlet

p_v = vapour pressure

w_{1s} = relative inlet velocity at shroud

z = number of blades

t_{1s} = blade thickness at leading edge near the shroud

D_{1s} = diameter at intersection of leading edge and shroud

D_{oh} = diameter of hub at impeller eye

$c_{m_{1s}}$ = meridional inlet velocity at shroud

c_{m_1} = mean meridional inlet velocity

The best cavitation performance will be obtained if the blade cavitation factor σ_b is minimum. Increasing the blockage coefficient q_{1s} and decreasing the hub/shroud diameter λ and the meridional velocity ratio c_r result in a smaller σ_b. The (theoretical) limits of the different quantities are:

$q_{1s} = 1$: no blockage, which occurs at zero blade thickness

$\lambda = 0$: no hub

$c_r = 1$: the meridional velocity at the shroud is equal to the mean inlet meridional velocity

$\sigma_b = 0$: the static pressure at the inlet equals the vapour pressure

As it is impossible to obtain the theoretical limits it is important to approach these values as near as possible. An inducer is more suited to do so for the following reasons:

- Because an inducer produces only a fraction of the head which is needed for the pump, a smaller number of blades than for an impeller alone can be used. Thus, at the same inlet diameter and inlet blade angle the blockage effect for an inducer is less than for an impeller alone.

- In general the meridional velocity at the shroud will be higher than the mean inlet meridional velocity, due to the curvature of the front shroud. To decrease the meridional velocity ratio c_r, the radius of curvature of the shroud must be as high as possible. An inducer can be provided with a cylindrical shroud with an infinitely great radius of curvature (in axial direction).

- By applying sweepback of the leading edge, the blockage effect, as well as the velocity ratio c_r can be reduced. Both result in a smaller value of σ_b. Manufacturing problems however prevent, for a great part, application of sweepback for impellers. The hubless inducer does not have these manufacturing limitations.

These considerations led to the choice of the inducer for the further development of sodium-pumps for extreme cavitation requirements.

A hubless inducer was preferred to an inducer with hub for the following reasons:

- Because the blade tips are fixed to the shroud, no tip cavitation can occur.
- For the same reason no blade tip losses can occur.
- Cavitation bubbles may be centrifuged to the open central core of the inducer and collapse there harmlessly. So a certain amount of cavitation will be allowable without damage to the inducer blades.
- A hydrostatic bearing can be placed on the outside surface of the cylindrical inducer shroud.
- If a bearing can be situated at the cylindrical shroud of the hubless inducer, vibrations may be reduced to a great extent.

Some disadvantages of the hubless inducer are:

- The pump efficiency decreases (1 to 2 %) due to enhanced friction losses of the rotating inducer shroud.
- The manufacturing of a hubless inducer is somewhat more complicated than that of an inducer with hub.
- There is a possibility of backflow through the open core of the impeller.

For the originally planned loop type SNR 2 sodium pump the hubless inducer was developed. The pool type pump asks for an inducer with a hub. One series of experiments, carried out end 1981, gave insight in the possible use of an inducer for a pool type sodium pump. However, some more experiments are still to be executed.

6. INDUCER MODEL DESIGN AND EXPERIMENTS.

Manufacturing

The first inducer model was made of perspex. The blades were machined from a solid block of material. Before the blades were screwed and glued to the cylindrical shroud, they were held together by a "hub", which was removed afterwards. The blades of a second model were made of steel and screwed to the shroud. This gave the possibility to test the inducer model with different numbers of blades. The shroud was made of perspex in order to examine the cavitation on the blade visually. It was fixed to the front shroud of the existing impeller.

Design features

To investigate the influence of the number of blades on the performance, the inducer could be tested with 2, 3, or 4 blades. Often an inducer is designed with a blade angle which is constant in axial direction. Consequently an incidence angle is needed to produce head. To minimize the blade cavitation factor, however, zero incidence at design point is necessary. So an increasing blade angle in axial direction, which provides a head at zero incidence, has been chosen.

It is known that sweepback of the blades has a favourable influence on the reduction cavitation behaviour of a pump; hence it is also applied to the inducer. The sweepback is obtained by cutting off the nose of the blades along the intersection line of the blades with a right circular cone. The axis of the cone coincides with the inducer axis, the base circle passes through the intersection point of the leading edge and the shroud. This means that in the meridional plane the leading edge is a straight line which intersects the axis at an angle of about 65°.

The leading edges of the blades were rounded off circularly in order to obtain the possibility to correct the inlet blade angle if necessary. Observed cavitation on either the suction side or the pressure side during the tests indicates in what direction the angles have to be changed. If cavitation occurs at the suction side, the blade angle must be decreased. This can be done by removing material from the suction side of the blade nose. If cavitation occurs at the pressure side, the angle is corrected by removing material from the pressure side. In general the adjustment of the blade angle is not constant along the leading edge and it is possible that for one part of the nose a positive and for the other part a negative correction of the blade angle may be necessary.

The blades consist of radial elements. Along such an element the tangent of the blade angle is inversely proportional to the radius. The inducer diameter is taken equal to the inlet diameter of the impeller (= diameter at impeller eye).

Testfacility

The measurements were carried out in a closed water test loop. The pressure in the test section can be lowered to achieve very low values of the suction pressure. A boosterpump provides the possibility to measure the low head parts of the characteristics. The efficiency is determined from measurements of the motor torque.

Cavitation can be observed through a perspex window in the wall of the circuit by means of stroboscopic lighting. A certain amount of cavitation defines the criterion "visual cavitation" which is used in the experiments. The value of the NPSH at which "visual cavitation" occurs is used to determine the suction specific speed S_A of the inducer, the impeller or the inducer-impeller combination.

Testresults

The first results of the inducer model tests were encouraging. The model with four blades gave the highest suction specific speed, but at a capacity smaller than the capacity at the best efficiency point. The best results were obtained with the inducer model with three blades. Therefore the remaining tests were performed with three blades. After correcting the inlet blade angle, as described in the preceding chapter, a suction specific speed $S_A = 15400$ in the best efficiency point was obtained. In this case, however, cavitation was observed at the suction side of the impeller blades, so cavitation on the impeller blades was decisive for the suction specific speed of the combination. Based on cavitation occurring at the inducer blades, a suction specific speed $S_A = 20480$ was realised. It is expected that redesign of the impeller is possible, so that a suction specific speed of about $S_A \approx 20500$ can be obtained for an inducer-impeller combination. The maximum efficiency was reduced by about 2%. This is mainly caused by the increase of the friction surface, especially the rotating cylindrical shroud.

The minimum cavitation factor $\sigma_{min.}$ for the inducer impeller combination is not only less than half the value of $\sigma_{min.}$ for the impeller alone, but it is also shifted towards the best efficiency point. A considerable reduction in the size of the pump is therefore possible. The results can be looked at in another way too. At the same size of the pump and the same NPSH the operating range, in which no cavitation occurs, is much more extended by applying an inducer.

The expected back flow in the central core of the inducer was not observed. This can be contributed largely to the impeller, which, for a great part, closes the open core.The pressure rise through the inducer near the axis is small.

7. CAVITATION AND ACOUSTIC NOISE MEASUREMENTS

Former work on this subject was published in /1-4/, the cavitation work on inducer development /10/ is summarized as follows.

Ref. nr. A: Measurements in water (1902/1900 combination).

Cavitation detection was initiated and measured by visualisation of the cavitation phenomenon (inspection through a window) and measuring a loss of head (0, 1 or 3 %) as a result of a decrease of the NPSH-A:

Definitions:
Incipient visual cavitation: the first bubbles on the surface of the impeller-blade or the impeller-blade canal. Permissible visual cavitation: a cavitation-film or a bubble on the surface of an impeller-blade, max. 5-10 mm in length.

Ref. nr. B: Measurements in water (1902/1903 combination).

The measurements (see afore) were expanded with acoustic noise analyses.
Equipment:

- Hydrophones, two Brüel and Kjaer (B and K)type 8100, at the suction and the discharge side and one Atlantic Research type LC 34 mounted on the venting vessel.
- One B and K amplifier type JJ2614 is connected with a frequency analyser B und K type 2107 and an octave filter B and K type 1612; a B and K recorder type 2305 was used for the registration in 1/3 octave bands to analyse the acoustic noise signals.
  The frequency range lies between 1000 and 40000 Hz. Acoustic signals with amplitudes of 5 dB - 30 dB were derived from measurements in cavitation experiments, performed with the impeller only or with the inducer-impeller combination.

Ref. nr. C: Inducer-Impeller combination (1904/1905).

The same apparatus as described under Ref. B. was used. The combination Ref. C (1904/1905) had poorer cavitation properties than the earlier combination Ref. B (1902/1903), because the design had not yet been optimized.

8. DISCUSSION OF RESULTS; see table 1

The aim of an inducer is the increase in the suction specific speed (S_A value) of a pump. Pumps are commonly available with S_A values in the range 8000 - 10000. With inducer-impeller combinations values up to $S_A = 15000$ are realistic.

Until now three major tasks A, B and C were executed, see table 1.

Experiments A. It was proven experimentally that an inducer-impeller combination could attain S_A values of over 11000; in fact, over 12600 has been reached successfully.

Experiments B. It was proven experimentally that an inducer-impeller combination for a loop type pump got an S_A value of 15400. For loop type pumps in general, however, an $S_A = 15000$ is practical whereby the specific speed (n_s) may be chosen in the range of 150 - 200.

Experiments C. The aim of the experiments is the design of pool type pumps. Therefore the n_s value may be chosen between 200 - 250. The main design goal here is the decrease of the L/D value; a hub type inducer can be used. Towards this goal preliminary experiments were carried out. The work has still to be continued, with special attention to:

a) the shape of the impeller blades, in order to optimise the design;

b) the restriction of the NPSH: an NPSH-R = 12 m is still a design criterium, main parameters for lowering the NPSH-R are:

$n \downarrow$ thus $n_s \downarrow$ in combination with
$D \uparrow$

Common pumps have efficiencies in the range 82-85%; for inducer-impeller combinations a lower must be accepted:80-83%

For the first two designs (A and B) a hubless inducer was used. For the preliminary design studies of case C a hubless inducer was originally used. This was based on the idea to use an impeller with a speed of 800 rpm, requiring a low NPSH (12 m).
However, since a low L/D value is advantageous for a pool-type pump, a reduction in the L/D ratio was studied.
At FDO experiments on the third pump (impeller-inducer combination C) were executed in 1981. Early 1982 and due to an unforeseen decrease in the budgets for the SNR 2 (or follow-up programme) this FDO-work was postponed.
The work on this third (C) inducer-impeller combination has not been fully concluded as only five experiments were performed. The five experiments (under C) are:

- two experiments without inducer;
- one experiment with a hubless inducer;
- two experiments wiht a hub inducer.

The results of the first "C" experiments, listed in table 1, are so far rather preliminary. To improve the NPSH demands of such a pump design future experiments are foreseen. The data given under "C" make reference to a Q = 5,47 m^3/s, H = 91 m pump with a realistic S_A = 13000, however requesting a relatively high NPSH.
This design ("C"), for a hub inducer-impeller combination, indicates remarkable advantages, despite of its requested relatively high NPSH, these advantages being:

- a short pump and a short pump-shaft;
- a free choice in the shaft arrangement;
- suitable for a pool reactor.

Continuation of this work in the future is one of the items in the proposed pool-programme.

9. APPLICATION FOR THE SNR-2 POOL TYPE LMFBR

See for details /19/.

The primary pump design for the SNR-2 pool type LMFBR as presented on the last figure is designed as a single stage, radial suction pump, with a free sodium level and operating in the vertical position. The major design characteristics are:

sodium flow (390°C)	20000 m^3/n
head	70 m
NPSH-A	12 m
speed	700 rpm
impeller diameter	1.1 m
total height (without drive)	15 m

Sodium inlet is by an annulus which is around the pressure piping. The primary pump is located in the cold sodium plenum. Design requirements for a primary pump of a pool type liquid metal cooled fast breeder reactor are strongly influenced by the necessary arrangement of the pumps in the reactor vessel. The main requirements are:

- The pump should be designed as compact as possible.

- The pump penetrates the fixed roof of the reactor vessel and is in the lower part of the pump connected with the grid plate. Special attention should be paid to thermal expansion effects.

So, on the basis of the afore mentioned requirements, a small diameter in connection with a high rotational speed is asked for. The rotational speed is influenced by required NPSH, critical speed and noise level. The design must have a short shaft to stay under critical with increased rotational speed and smaller impeller diameter.

In the actual design of the SNR-2 primary pump the rotational speed is 700 rpm (under critical). However, a supercritical shaft, may be advantageous since it gives a reduction in shaft diameter. The mass of the shaft can be reduced with a factor of about 12 and consequently also the vibration energy due to unbalance or asymmetrical temperature distribution.

A supercritical shaft requires sufficient damping. For this, the behaviour of the hydrostatic bearings is essential. To investigate the vibrational behaviour of a supercritical shaft in connection with hydro-static bearings a test rig is available now. Tests can be carried out through the European cooperation on R & D for LMFBR's.

Conclusions

1. The development of inducers proved that a suction specific speed of S_A = 15400 is possible for an optimum inducer impeller combination.

2. Inducers are very valuable for nuclear duties. For the system requirements of next generation reactor pumps a diameter reduction of nearly 30% can be reached with an inducer. This means a reduction in weight and costs of at least 30%.

3. Because, in fact, an inducer is a high specific speed impeller, instabilities can be expected in the lower capacity region. Though it is not extensively investigated, no instabilities have been observed during the tests at capacities above about 40% of design flow.

4. Pumps with electric motor drive often are restricted in speed e.g. if a speed of 2500 rpm is allowable in relation to the cavitation requirements, a motor of 1500 rpm must be chosen.
   A motor of 3000 rpm, however, can be applied with an inducer pump resulting in a considerable reduction of size and costs.

5. Preliminary studies on the influence on the cavitation behaviour of the fluid to be pumped, give the following indications. Hydraulic tests in water are, to a great extent, representative for sodium and potassium pumps. In both cases the Stepanoff number of these liquid metals at normal operating temperature are of the same order of magnitude, though somewhat lower than that of water at ambient temperature. This means that the sensitivity for cavitation in these fluids is lower than in water.

6. Applications of inducers in other fluids than sodium and water are useful in all cases where the available suction pressure is low and the pump drive allows a higher speed. A high suction specific speed is valuable for size reduction of all pumps, also for pumps in other than the nuclear industry.

Recommendations

1. The inducer development was started in the first place to have sodium pumps for fast breeder reactors available which:
   a. have minimum dimensions to minimize the dimensions and the weigth of the reactor internals;
   b. have a good efficiency;
   c. are not subject to erosive cavitation to quarantee a lifetime of 40 years;
   d. can be manufactured in an easy way.

   These aims were for the greater part obtained. For instance: with the inducer the diameter of the primary pumps for a next generation reactor can be reduced by ca. 30%.

2. To allow an optimal design of the proposed SNR 2 pool type primary pomp some more experiments are recommended. This because only one experiment with a hub type inducer was carried out until now.

Symbols

c	Absolute velocity	$/m.s^{-1}/$
c_r	Meridional velocity ratio	$/m.s^{-1}/$
D	Diameter	$/m/$
H	Head	$/m/$
NPSH	Net positive suction head	$/m/$
NPSH-A	Available NPSH	$/m/$
n	Speed	/rpm/
n	Specific speed $(=\omega\sqrt{Q}/(g.H)^{\frac{3}{4}})$	/ - /
p	Static pressure	/bar/
P_v	Vapour pressure	/bar/
q	Blockage coefficient	/ % /
Q	Flow capacity	$/m^3 s^{-1}/$
S_ω	Suction specific speed $(=\omega\sqrt{Q}/(g.NPSH)^{\frac{3}{4}})$	/ - /
S_A	Suction specific speed $(= n\sqrt{Q}/NPSH^{\frac{3}{4}})$ (rpm, USGPM, ft)	/ * /
t	Blade thickness	/mm/
u	Peripheral velocity	$/m.s^{-1}/$
w	Relative velocity	$/m.s^{-1}/$
z	Number of blades	/ - /
β	Blade angle	/ ° /
λ	Hub-diameter ratio	/ - /
η	Efficiency	/ % /
σ	Thoma's cavitation coefficient(=NPSH/H)	/ - /
ρ	Specific mass	$/kg.m^{-3}/$
σ	Blade cavitation factor	/ - /
ϕ	Flow coefficient $(=Q/\omega\ D\ \frac{3}{2})$	/ - /
ψ	Head coefficient $(=gH/^{\omega}\ D_2)$	/ - /
ω	Rotational speed	$/\ s^{-1}/$
*	American Units	

Subscripts

1	Leading edge
2	Trailing edge
m	Meridional
s	Shroud

Definitions:

$$n_s = \frac{3,65\ n\sqrt{Q}}{H^{\frac{3}{4}}}\ ; \quad n = \frac{\omega\ \sqrt{Q}}{(g\ H)^{\frac{3}{4}}}$$

$$S_A = \frac{51,7\ n\sqrt{Q}}{NPSH^{\frac{3}{4}}}\ ; \quad S_\omega = \frac{\omega\ \sqrt{Q}}{(g\ NPSH)^{\frac{3}{4}}}$$

$$\omega = \frac{2\ \pi\ .\ n}{60}$$

$$\sigma = \frac{NPSH}{H}$$

Conversion values:

$$n_s = 193,2\ n_\omega$$

$$S_A = 2736,6\ S_\omega$$

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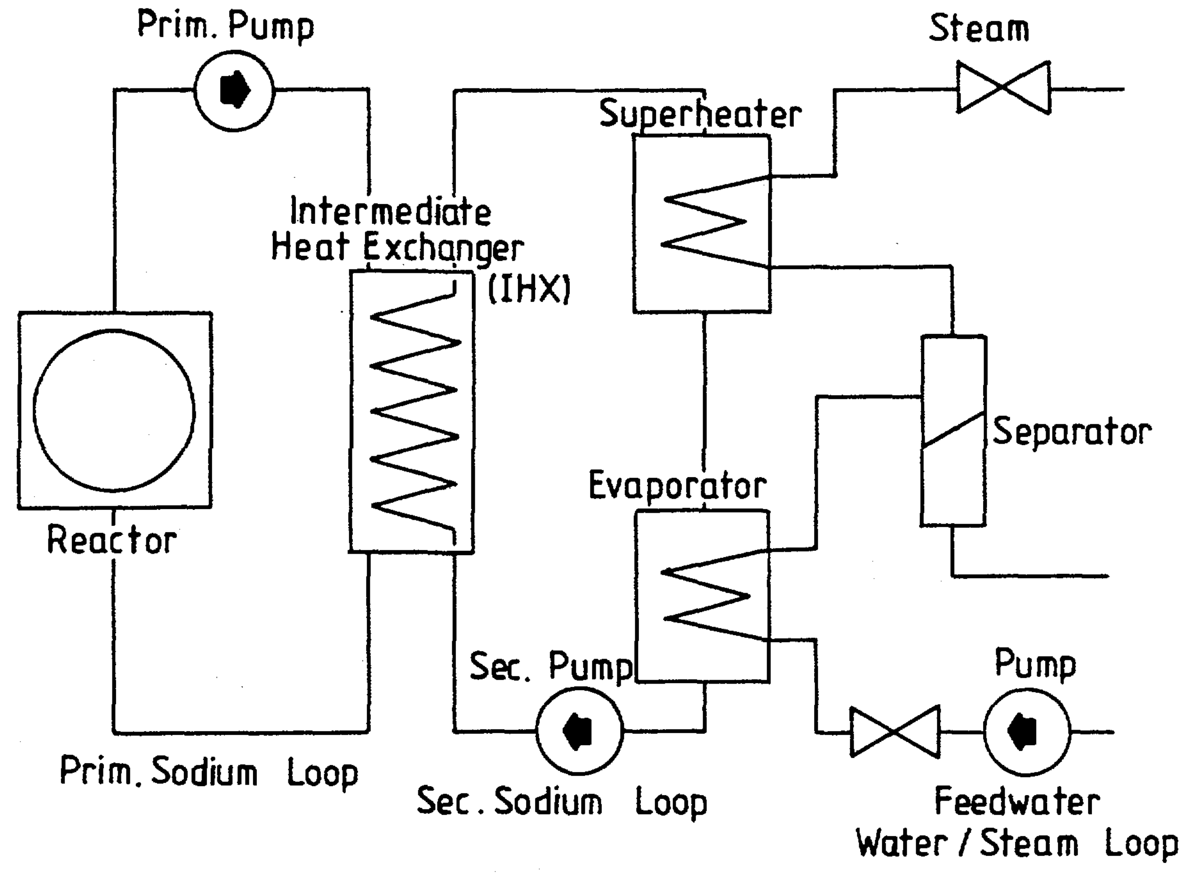
Pages 96-106 of the minutes.

		Dimensions	Hubless design		Design with a hub Preliminary results	
			A. first series of tests. Loop type primary pumps	B) 2nd series of tests Design and Tests '79-'81 Loop type primary pump	referencedesign for a SNR-2 pool primary pump.	C experiments in '81 amongst others one test with a Rub type inducer/ impeller
Q	capacity	[m^3/s]	6,02	5,47	5,47	5,47
H	head	[m]	160	120	70	91
NPSH-R		[m]	20,3	11,7	12	16,4
σ	Thoma nr.	[-]	0,127	0,098	0,171	0,180
η	efficiency	[%]	79	82	78	79
n	speed	[rpm]	951	807	700	883
ω	angular speed	[s^{-1}]	99,6	84,5	73,3	92,5
n_s	spec. speed	[*]	189	190	247	256
n_ω	spec. speed	[-]	0,98	0,98	1,28	1,32
S_A	suction spec. speed	[*]	12600	15400	13100	13100
S_ω	suction spec. speed	[-]	4,6	5,6	4,8	4,8
D_{IMP}	imp. diam.	[m]	1,3	1,3	1,1	1,1
L/D	ratio	[-]	0,9	0,87	0,8	0,67
FDO Nr.		[-]	1902/1900	1902/1903		1904/1905

Table 1 FDO-Testresults of Inducer/Impeller combinations for SNR-2 primary pumps

*) in american units (see definitions and also open literature on pumps)



Schematic representation of LMFBR heattransfer system

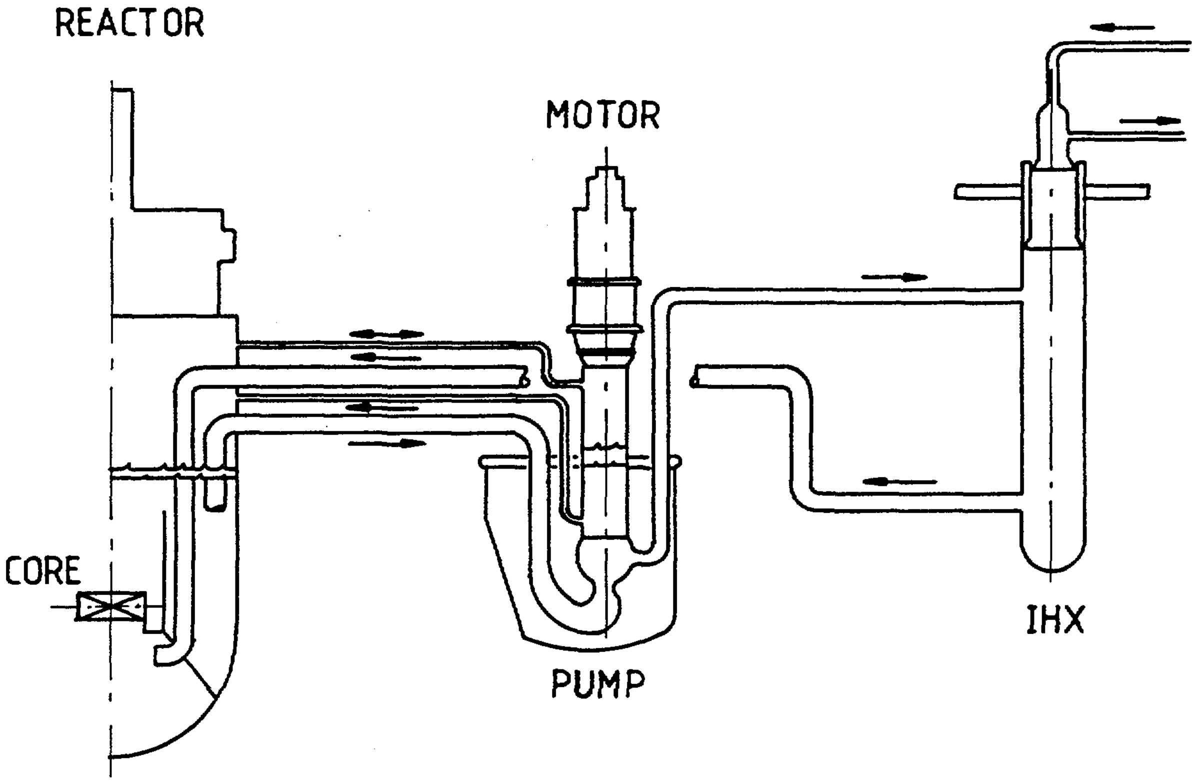
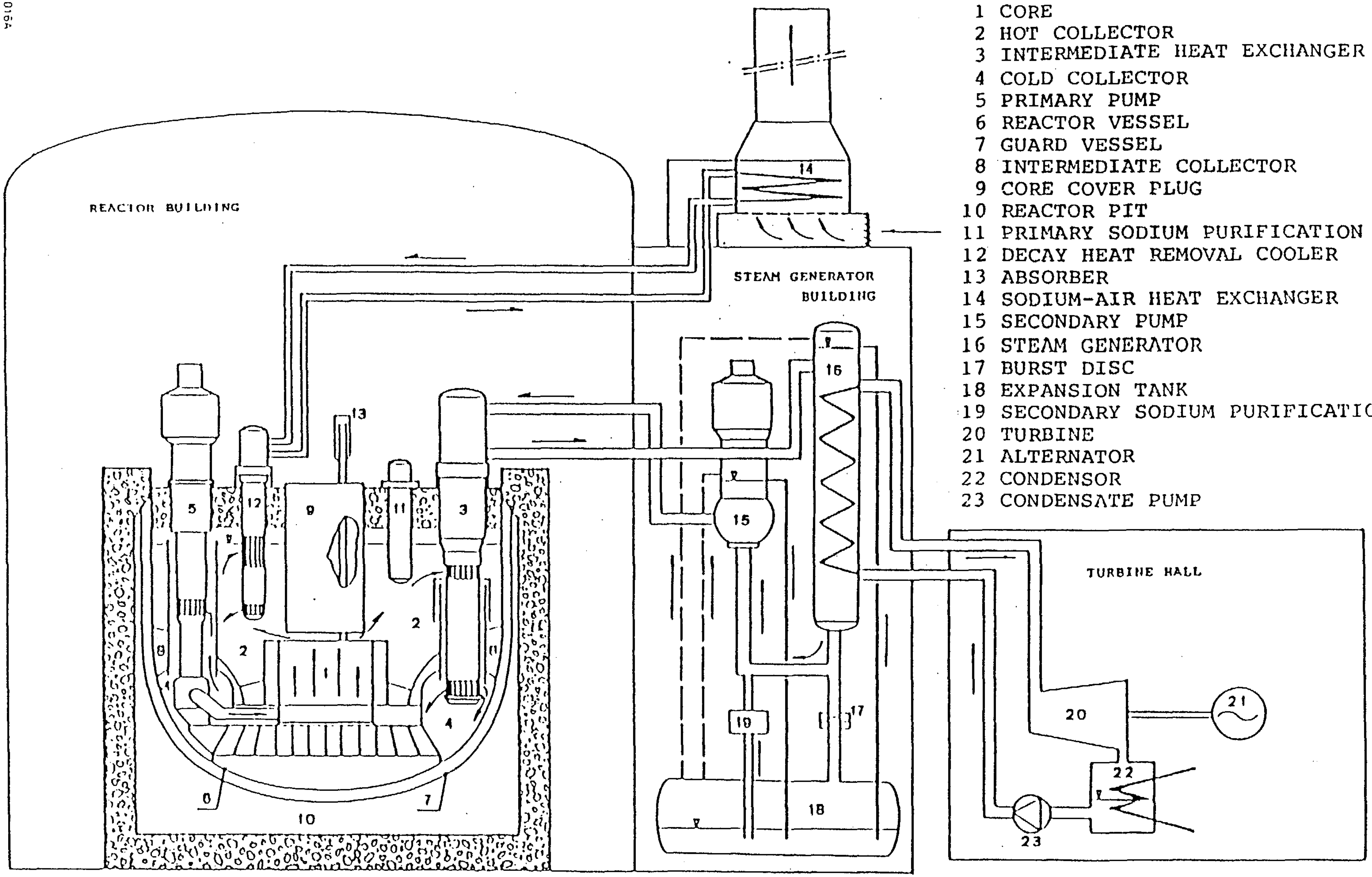


Fig. 1: LAY-OUT SNR PRIMARY CIRCUIT
(loop type SNR 300)



1	CORE
2	HOT COLLECTOR
3	INTERMEDIATE HEAT EXCHANGER
4	COLD COLLECTOR
5	PRIMARY PUMP
6	REACTOR VESSEL
7	GUARD VESSEL
8	INTERMEDIATE COLLECTOR
9	CORE COVER PLUG
10	REACTOR PIT
11	PRIMARY SODIUM PURIFICATION
12	DECAY HEAT REMOVAL COOLER
13	ABSORBER
14	SODIUM-AIR HEAT EXCHANGER
15	SECONDARY PUMP
16	STEAM GENERATOR
17	BURST DISC
18	EXPANSION TANK
19	SECONDARY SODIUM PURIFICATION
20	TURBINE
21	ALTERNATOR
22	CONDENSOR
23	CONDENSATE PUMP

Fig 2 General scheme SNR 2 (pool type)

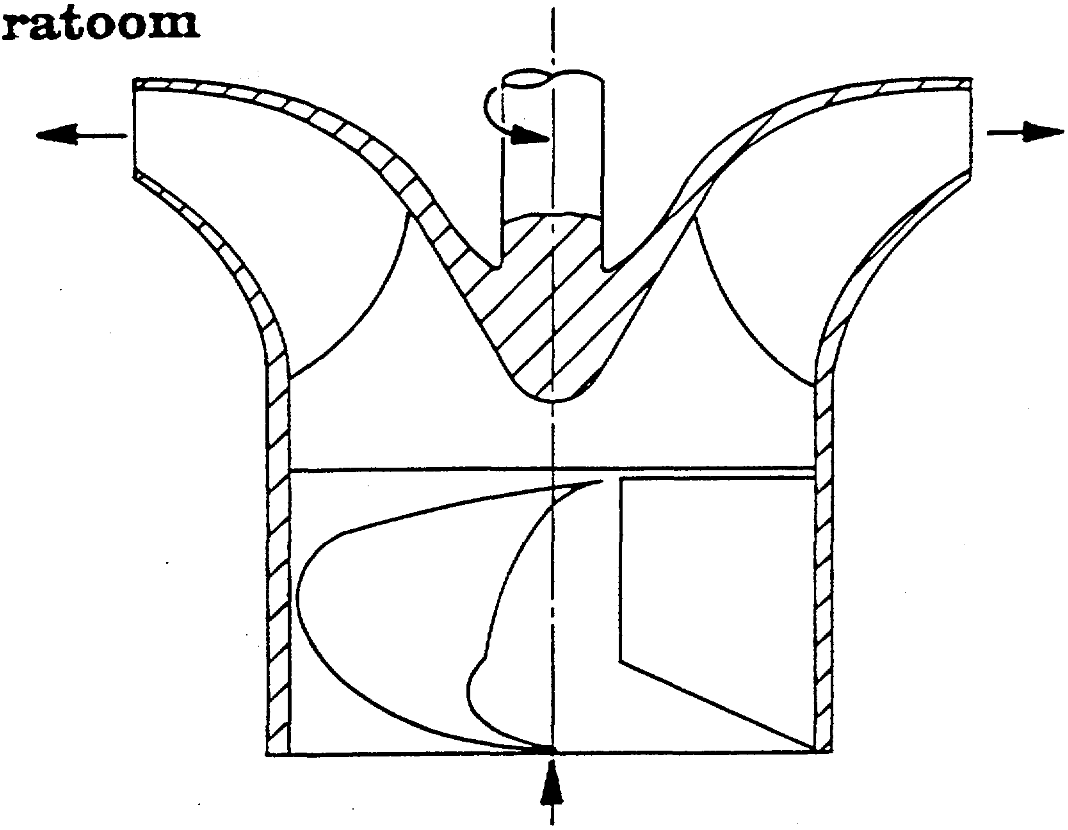


FIG. 3: CONFIGURATION OF INDUCER/IMPELLER COMBINATION

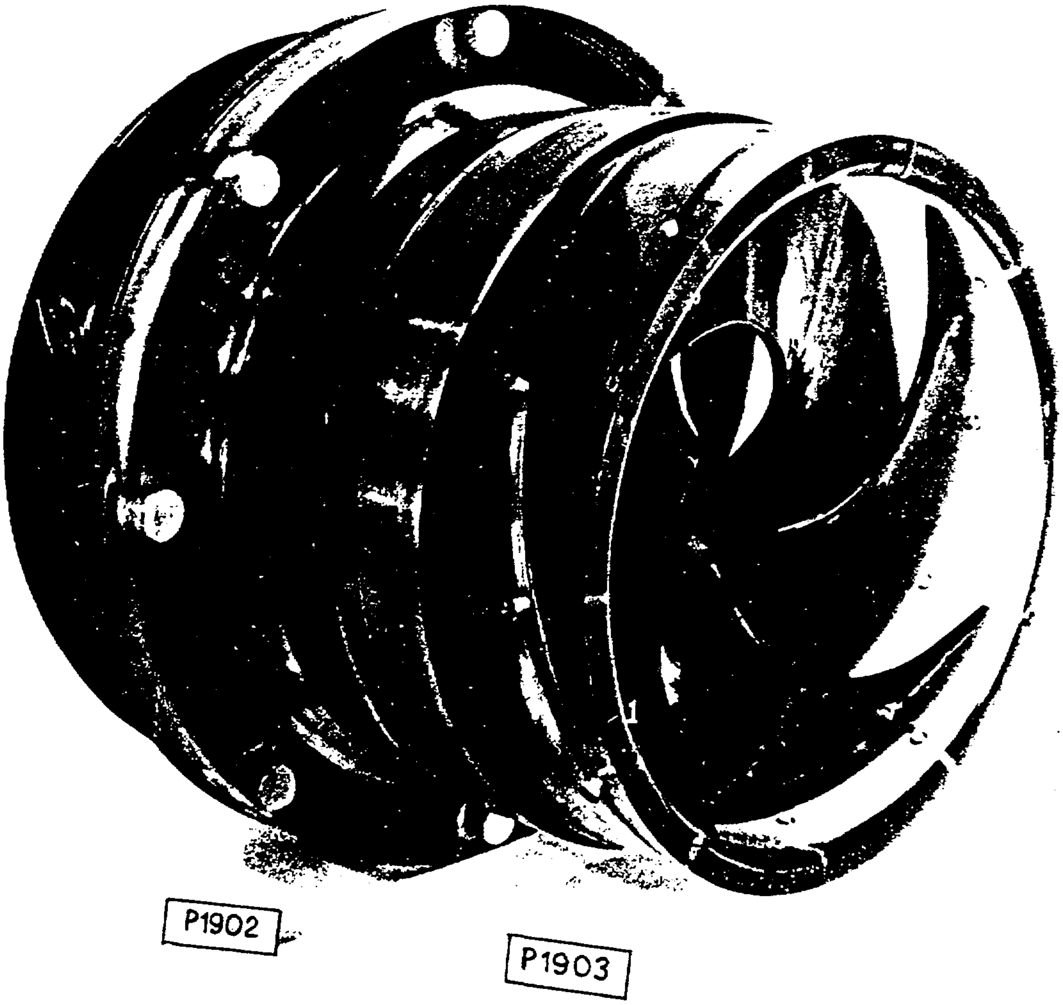


FIG. 4: INDUCER/IMPELLER COMBINATION

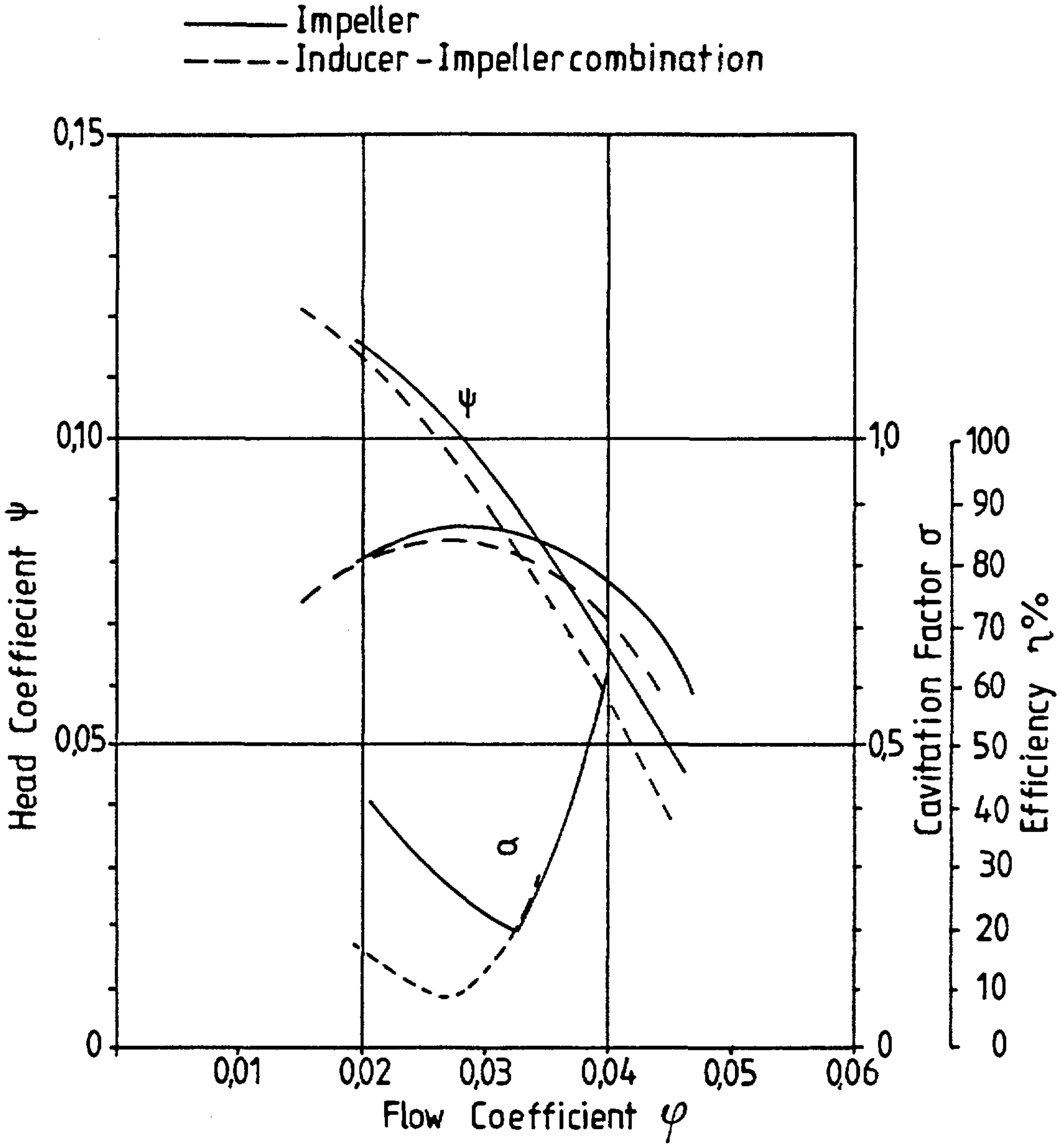


FIG 5: PERFORMANCE CURVES OF THE INDUCER IMPELLER COMBINATION AND THE SEPARATE IMPELLER.

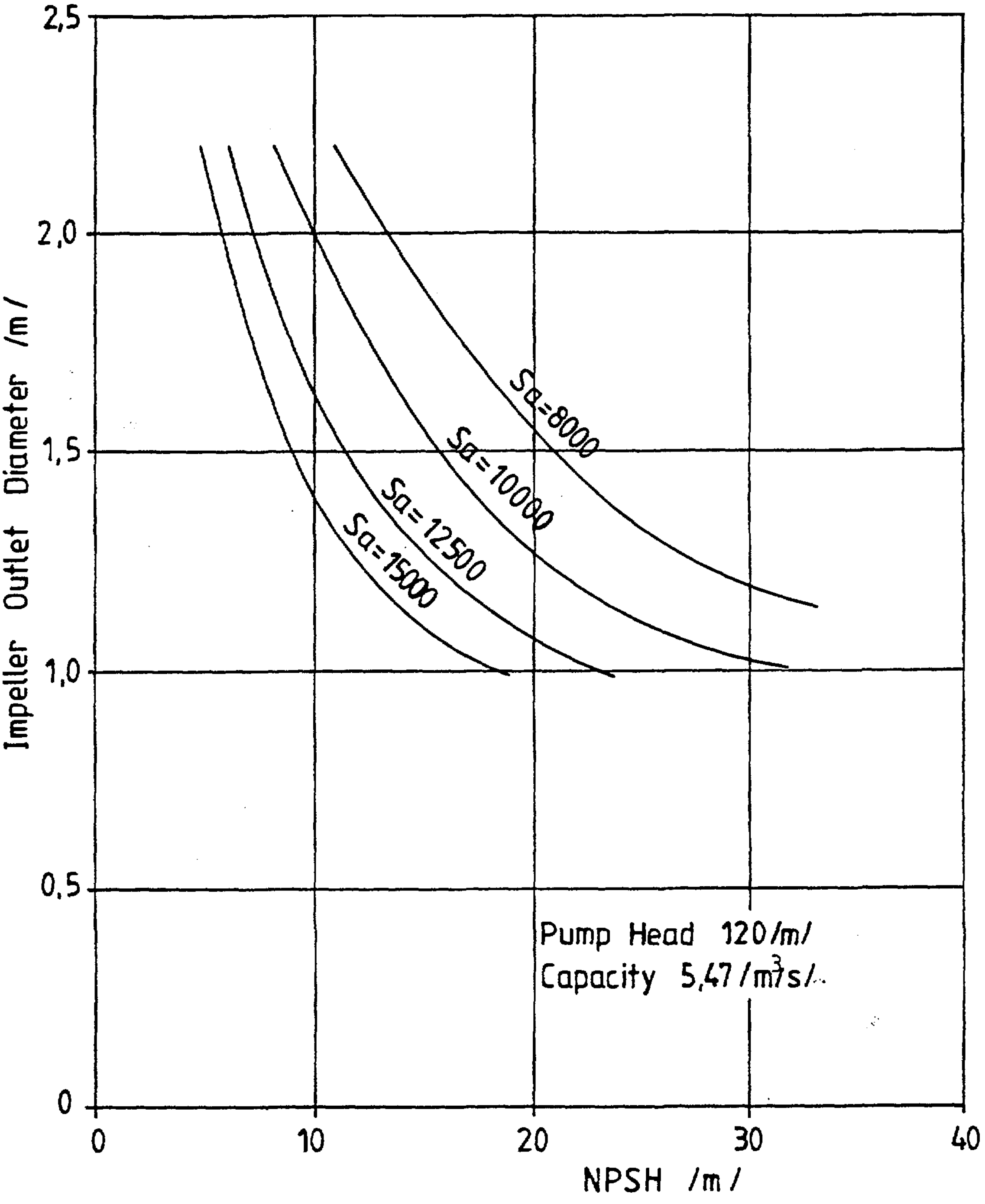


FIG 6: RELATION BETWEEN IMPELLER OUTLET DIAMETER AND NPSH, DEPENDING ON THE SUCTION SPECIFIC SPEED.

PUMP 1

$Q = 5{,}47 \; m^3/s$

$H = 120 \; m$

NPSH-R = 11,6 m

$n = 520$ rpm

$n_s = 122$

$S_A = 10000$

PUMP 2

$Q = 5{,}47 \; m^3/s$

$H = 120 \; m$

NPSH-R = 11,7 m

$n = 807$ rpm

$n_s = 190$

$S_A = 15400$

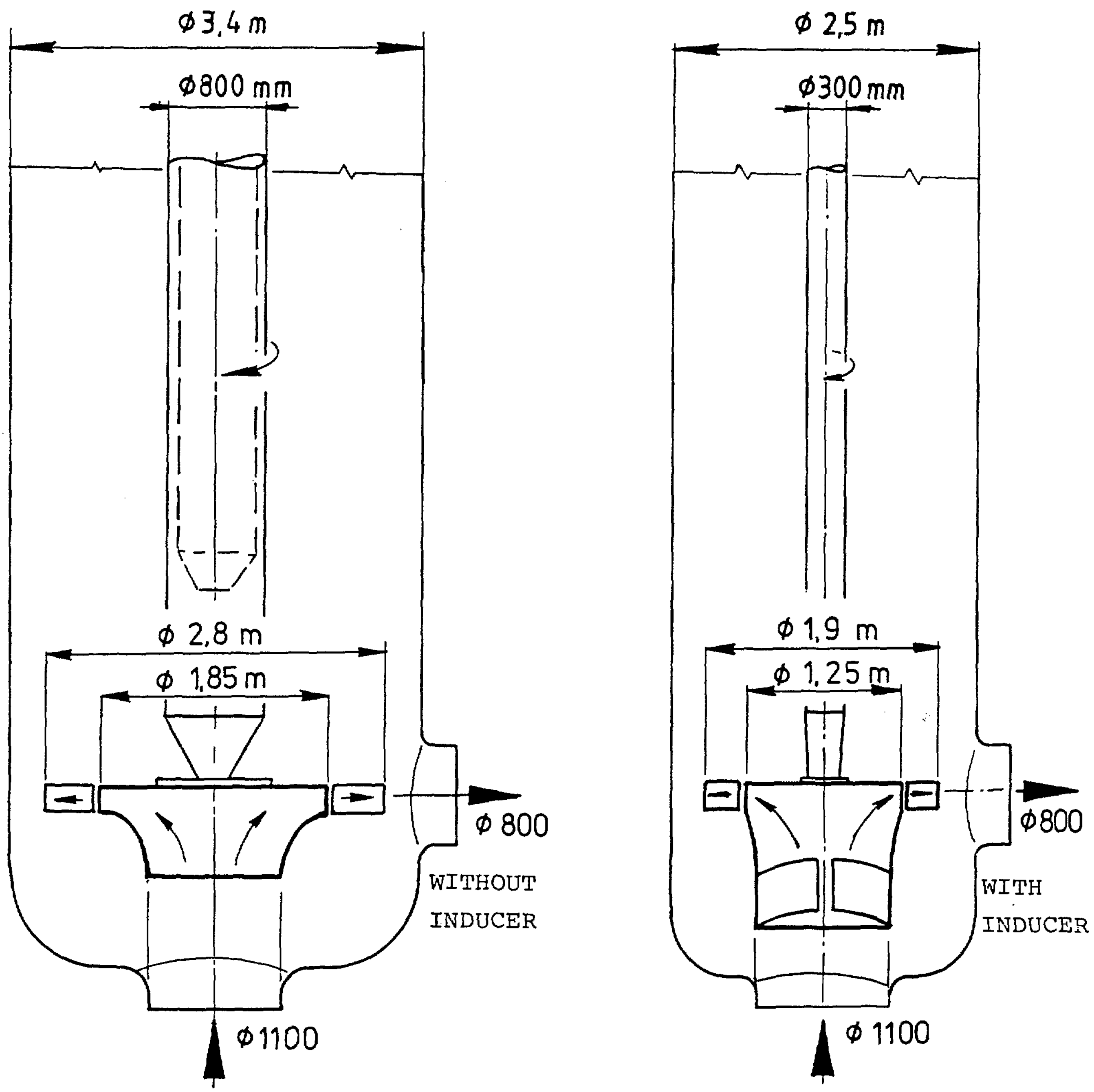


FIG. 7: COMPARISON OF A LOOP TYPE PUMP, WITH AND WITHOUT AN INDUCER; PRINCIPLE LAY-OUT.

PUMP 5

Q = 5,47 m^3/s
H = 91 m
NPSH-R = 11,6 m
n = 520 rpm
n_s = 151
S_A = 10000

PUMP 6

Q = 5,47 m^3/s
H = 91 m
NPSH-R = 11,7 m
n = 680 rpm
n_s = 197
S_A = 13000

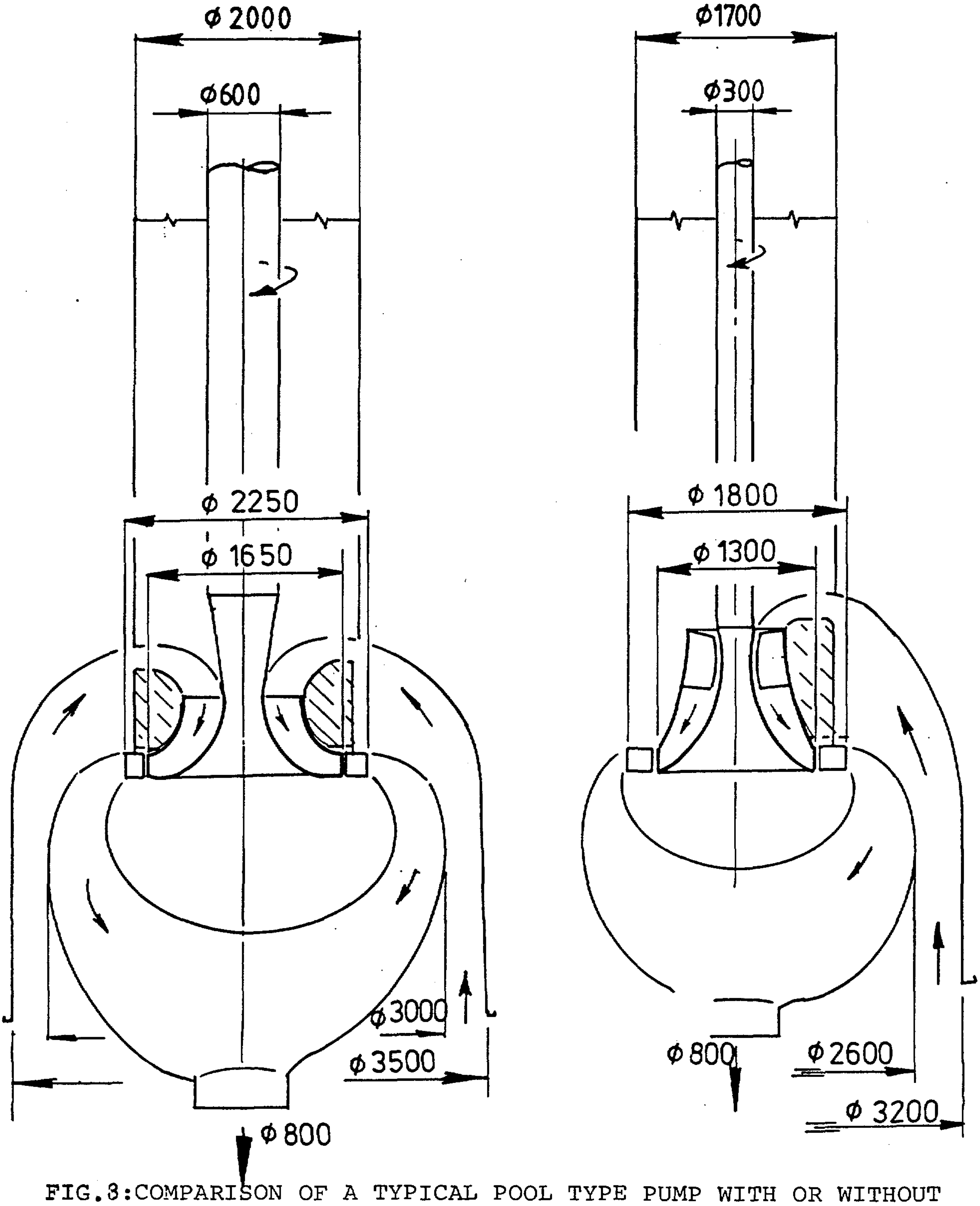


FIG.3:COMPARISON OF A TYPICAL POOL TYPE PUMP WITH OR WITHOUT A HUB TYPE INDUCER; PRINCIPLE LAY-OUT.

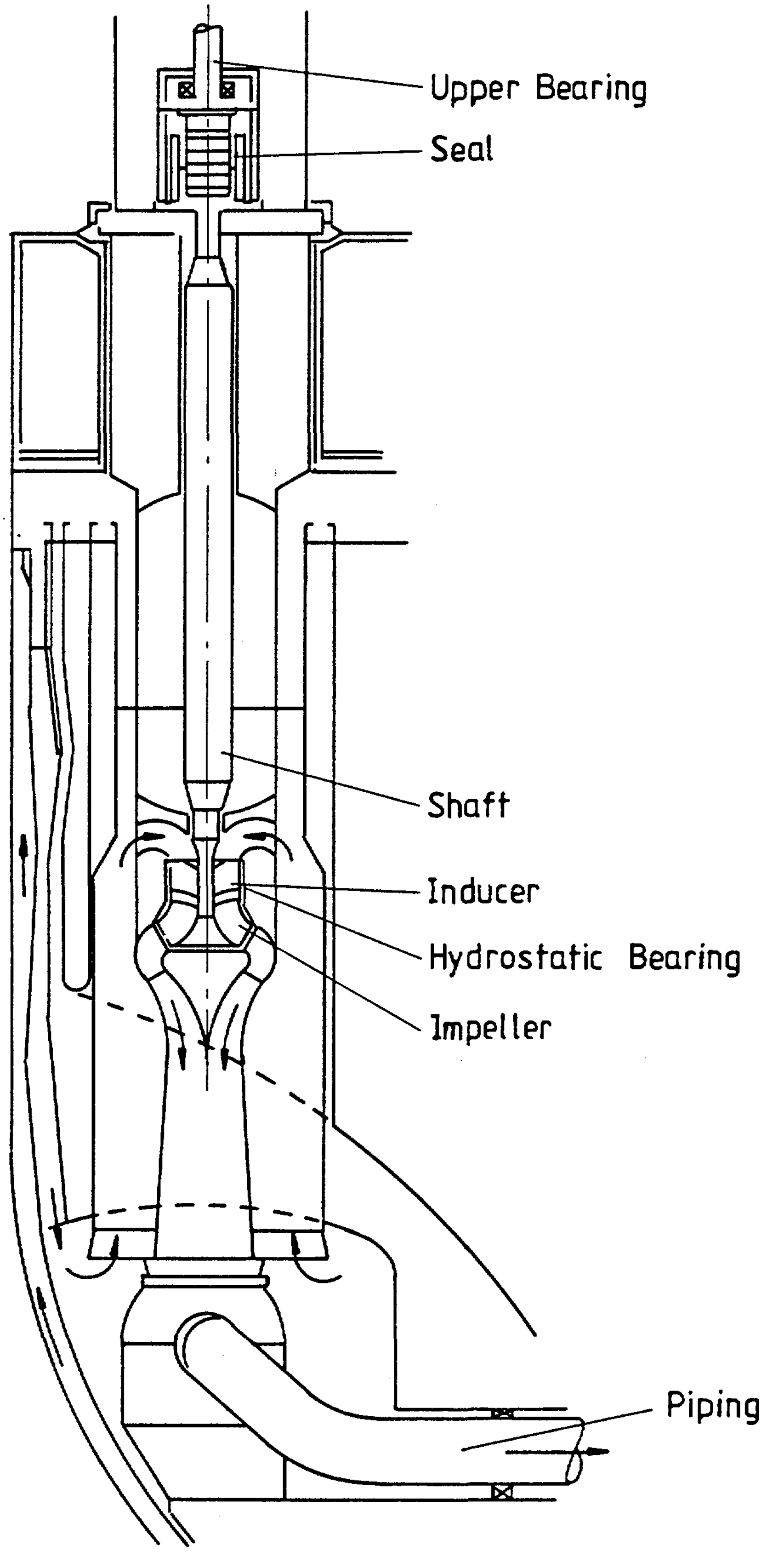
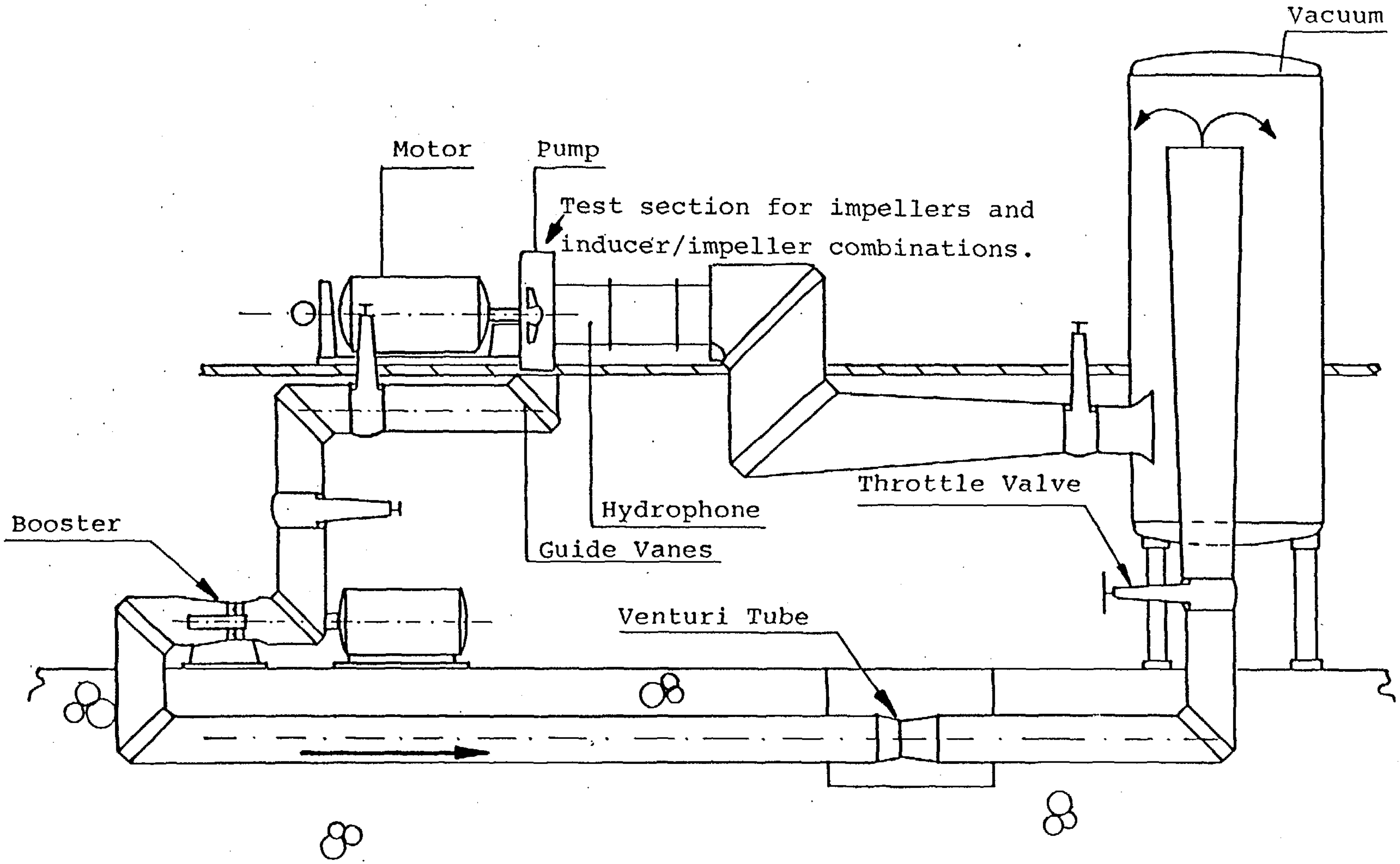


FIG. 9: CONCEPT ON POOLTYPE PUMP WITH INDUCER.



Motor power - 75 kW
Test speed - 1000 rpm
Max.Impeller diameter - 0,44 m
Fluidium - water

Max.Discharge pressure - 5 bar
Max.Pressure suctionside - 2,5 bar
Min.Pressure suctionside - 0,1 bar

Fig.10 :Water test-rig for impellers, inducers or impeller-inducer combinations.