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Computational Fluid Dynamic Analysis of Boiler Feed Pump by Varying Blade Numbers

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Abstract - Feed pumps are an essential subsystem of boilers used in industrial process plants and called as boiler feed pump (BFP). Normally, BFP is high pressure unit that takes suction from condensate return system and can be of the centrifugal type pump. In centrifugal pump, water enters axially through the impeller eyes and exits radially. Generally, electric motor is used as prime mover to run the feed pump. To force water into boiler, the pump must generate sufficient pressure to overcome steam pressure developed by boiler. In the present study, design and analysis of boiler feed pump having a flow of 50kg/s, rotational velocity of 2000Rpm and operating at 70 deg C has been taken up. The various pump parameters are obtained from design and pump model is developed using modeling software solid works to evaluate the results at given operating conditions, CFD analysis is carried out using Solid works flow simulations module. Blade number has great influence on the pump performance. Therefore, CFD analyses are carried out for the pump with 6, 7 and 8 blades.

Based on performance of every pump model, the best feed pump design is selected. A steady state CFD analysis is carried out using the K-ε turbulence model to solve for the Navier-Stroke's equation.

Three different geometry of 6,7,8 no's of impeller blade is modelled in solid works 2016 software, Computational fluid dynamic analysis is performed in solid works 2016 module.

Index Terms - CFD, Solid Works, boiler feed pump, centrifugal, turbulence.

1. INTRODUCTION

Pumps have continued to grow in size, speed and energy level, revealing new problems that are being addressed by innovative materials and mechanical and hydraulic design approaches. Pump and its components must have reliable performance without any leakage. Centrifugal pumps are used in a wide range of applications and they can handle a variety of liquids like boiler feed water at relatively high pressures and/or temperatures. The present work focuses on high energy, double volute pump, it should be operating without leakage while subjected simultaneously maximum allowable working pressure (M.A.W.P.) and maximum operating temperature. However, due to the high energies involved these pumps tend to suffer more pressure pulsations than single stage pumps. Hence for satisfactory performance it is intended to do the various analyses like structural analysis, Seismic analysis. So that the important part of pump shall be designed and possibility of failure would be examined and necessary geometric modification will be applied to the model.

The design and arrangement of boiler feed pumps has a significant impact on overall unit availability, In determining the optimum arrangement of feed-pumping plant, the economic assessment needs to take account of capital costs, capitalized running costs, repair and maintenance costs, and the likely effects of loss of availability.

The provision of sufficient pumping capacity to meet flow requirements under all operational circumstances. It is normal practice to include a flow margin to accommodate additional demand by the turbine above its design rating during transient flow disturbances. A margin on pump generated head is also appropriate to cover for deterioration resulting from internal wear during periods between overhaul. In the interests of keeping pump set sizes and powers to a reasonable minimum, consistent with maintaining the pump best efficiency close to the duty point operation, these margins have been optimized as 5% on flow and 3% on generated head.

Constraints should be considered

- The need to ensure that failure of a single pump set does not impair the start-up of the main unit or affect output capability. Standby capacity equivalent to the largest duty pump set is indicated with a rapid start-up capability, sufficient to prevent the loss of boiler drum level and consequent unit trip.
- The need to ensure that the plant is able to operate satisfactorily during and after a large load rejection by the turbine-generator unit. This requires that the drives for the duty pumps and their power supplies must be suitable for this operating condition. Alternatively, a suitable rapid start/standby pump set is necessary.
- The need to provide adequate NPSH margins, taking into account that the pumps are supplied from a direct contact heater (de-aerator), which can be subject to pressure decay following a reduction in turbine load.

- There should be at least two pump sets capable of starting the unit. If a turbine drive is to fulfill this function, then a steam supply independent of the main boiler (i.e., an auxiliary boiler) is required.
- If two or more pumps are required to operate in parallel, then the pump sets should be able to accommodate run-out duties following loss of an operating pump.

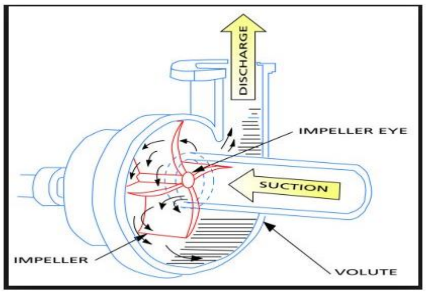

Fig: Boiler feed pump working

PUMP

Types of pumps

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps.

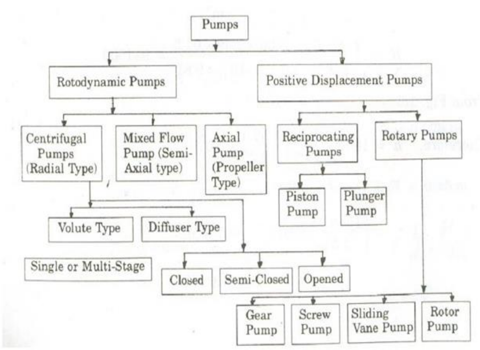

Fig 1.1 pumps classifications

Pump services in Main Steam Cycle

1. Turbo generator and auxiliaries
    - Screen wash-water pumps
    - Cooling tower make-up pumps
2. Steam generator equipment
    - Condensate pumps
    - Condensate booster ums
    - Boiler-feed pumps
    - Boiler-feed booster pumps
    - Heater drain pumps (low and high pressure)

Pump is a machinery or device for raising, compressing or transferring fluid. It moves fluids or sometimes slurries, by mechanical action. It operates by some mechanism and consumes energy to perform mechanical work by moving the fluid. It operates via many energy sources, including manual operation, electricity, engines, or wind power.

They come in many sizes, from microscopic for use in medical applications to large industrial pumps. Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water cooling and fuel injection etc.

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Mechanical pumps serve in a wide range of applications such as pumping water from wells, aquarium filtering, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers. In the medical industry, pumps are used for biochemical processes in developing and manufacturing medicine, and as artificial replacements for body parts, in particular the artificial heart and penile prosthesis.

Single stage pump – When in a casing only one impeller is revolving then it is called single stage pump.

Double/multi-stage pump – When in a casing two or more than two impellers are revolving then it is called double/multi-stage pump.

Pumps are mainly classified in two broad classes:

a.Displacement

The liquid or gas is displaced from the suction to the discharge by the mechanical variations of the volume of chambers. They can be subdivided in two classes:

Reciprocating pump

In this a plunger or piston is mechanically reciprocated in a liquid cylinder.

b.Rotary pumps

In this the liquid is forced through the pump cylinder or casing by means of screw or gears.

Centrifugal

Flow through the pump is induced by the centrifugal force imparted to the liquid by the rotation of an impeller or impellers

Pump Selection

From the information supplied in the data sheet, a pump can normally be selected from the pump manufacturer's sales book. These are normally divided into sec- tions, each representing a particular construction. Performance maps show the range of capacity and head available, while individual performance curves show efficiency and NPSHR. If the pump requirements fall within the performances shown in the sales book, the process of selection is relatively simple. When the re- quired pumping conditions, however, are outside the existing range of perfor- mance, selection is no longer simple and becomes the responsibility of the pump designer.

Definition of Pump Specific Speed and Suction Specific Speed

Pump specific speed (Ns) as it is applied to centrifugal pumps is defined in U.S. unitsas:

$$N_s = \frac{RPM \times GPM^{.5}}{H^{.75}}$$

Specific speed is always calculated at the best efficiency point (BEP) with maximum impeller diameter and single stage only. As specific speed can be calculated in any consistent units, it is useful to convert the calculated number to some other sys- tem of units. See Table 2-1. The suction specific speed (Nss) is calculated by the same f ormula as pump specific speed (Ns) but uses NPSHR values i n feet in place of head (H) in feet. To calculate pump specific speed (Ns) use full capacity (GPM) for either single- or double-suction pumps. To calculate suction specific speed (Nss) use one half of capacity (GPM) for double-suction pumps.

Table Specific Speed Conversion

UNITS Capacity	Head/ Stage	U.S. to Metric Multiply By	Metric to U.S. Multiply By
Ft^3/Sec	Feet	.0472	21.19
M^3/Sec	Meters	.0194	51.65
M^3/Min	Meters	.15	6.67
M^3/Hr	Meters	1.1615	.8609

$$N_{ss} = \frac{RPM \times GPM^{.5}}{NPSHR^{.75}}$$

It is well known that specific speed is a reference number that describes the hy- draulic features of a pump, whether radial, semi-axial (Francis type), or propeller type.

BOILER FEED PUMP

Boiler feed pumps are also referred to as feed pumps (see Reactor pump) and designed as multistage radial flow pumps. (Also see Multistage pump.)

They serve to feed a steam generator such as a boiler or a nuclear reactor with a quantity of feed water corresponding to the quantity of steam emitted. Today, all boiler feed pumps are centrifugal pumps.

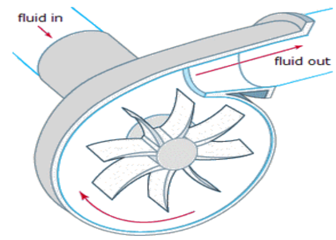


Fig: centrifugal boiler feed pump

A Centrifugal pump is a mechanical device for moving air or other gases or fluid.

They use the kinetic energy of the impellers or the rotating blade to increase the pressure of the air/gas/liquid stream which in turn moves them against the resistance caused by ducts, dampers and other components. Centrifugal fans accelerate air radically, changing the direction (typically by 90°) of the airflow. They are sturdy, quiet, reliable, and capable of operating over a wide range of conditions.

Centrifugal pump are constant displacement devices or constant volume devices, meaning that, at a constant fan speed, a centrifugal fan will pump a constant volume of air or water rather than a constant mass. This means that the velocity in a system is fixed even though mass flow rate through the fan is not.

Centrifugal pumps which belong to wider group of fluid machines called turbo machines are the most common type of pump used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward or axially into a diffuser or volute chamber, from where it exits into the downstream piping system. Centrifugal pumps are typically used for large discharge through smaller heads.

Computational fluid dynamics (CFD) analysis is being increasingly applied in the design of centrifugal pumps. With the aid of the CFD approach, the complex internal flows in water pump impellers, which are not fully understood yet, can be well predicted, to speed up the pump design procedure. Thus, CFD is any important tool for pump designers. The use of CFD tools in turbo machinery industry is quite common today. Recent advances in computing power, together with powerful graphics and interactive 3D manipulation of models have made the process of creating a CFD model and analyzing results much less labour intensive, reducing time and, hence, cost. Advanced solvers contain algorithms which enable robust solutions of the flow field in a reasonable time. As a result of these factors, Computational Fluid Dynamics is now an established industrial design tool, helping to reduce design time scales and improve processes throughout the engineering world.

Purpose of Boiler feed pump:

BFP supply feed water for boiler drum in a power plant. In our case BFP supply feed water mainlyfor HP and IP drum. Feed water also required for:

HP Bypass Spray water

HP attemperator spray

HRH attemperator spray

Gland Steam/ Aux steam de-super heating.

Velocity triangle:

A diagram called a velocity triangle helps us in determining the flow geometry at the entry and exit of a blade. A minimum number of data are required to draw a velocity triangle at a point on blade. Some component of velocity varies at different point on the blade due to changes in the direction of flow. Hence an infinite number of velocity triangles are possible for a given blade. In order to describe the flow using only two velocity triangles we define mean values of velocity and their direction. Velocity triangle of any turbo machine has three components as shown

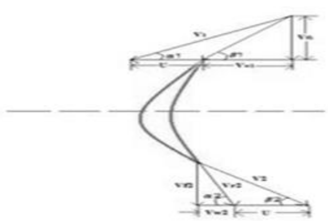


Fig: Velocity triangle for forward facing blade

These velocities are related by the triangle law of vector addition:

$$V = U + V_r$$

Where

U= Blade velocity

Vr = Relative Velocity

V = Absolute velocity

This relatively simple equation is used frequently while drawing the velocity diagram. The velocity diagram for the forward, backward face blades shown are drawn using this law. The angle α is the angle made by the absolute velocity with the axial direction and angle β is the angle made by blade with respect to axial direction.

Blower efficiency and performance

Pump efficiency is the ratio between the power transferred to the water stream and the power Delivered by the motor to the pump.The power of the water flow is the produc to the pressure and the flow, corrected for unit consistency.

Another term for efficiency that is often used with fan as is static efficiency,which use static pressure instead of total pressure in estimating the efficiency. When evaluating pump performance, it is important to know which efficiencytermis being used.

The pump efficiency depends on the type of pump and impeller. As the flow rate increases, the efficiency increase to certain height ("peakefficiency") and then decreases with further increasing flowrate (Figure2.3). The peak efficiency ranges for different types of centrifugal and axial impeller blades are given in Table

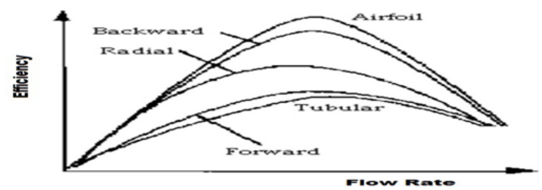


Fig Efficiency versus Flow rate

Table: Efficiency of Various blades pump

Type of Centrifugal pump	Peak Efficiency Range
Airfoil, Backward curved/inclined	79-83
Modified radial	72-79
Radial	69-75
Pressure Blower	58-68
Forward Curved	60-65

Centrifugal pump performance is typically estimated by using a graph that shows the different pressures developed by the pump and the corresponding required power. The manufacturers normally provide these pump performance curves. Understanding this relationship is essential to designing, sourcing, and operating a fan system and is the key to optimum impeller selection.

Industrial boiler feed water pumps for clean water & steam

Industrial boilers, for example on board a marine vessel, in a large industrial factory or power plant, are fed either fresh water or steam by a high pressure boiler feed pump. As the water or steam is fed round a system, they are sometimes referred to as boiler circulation pumps. As taking suction from a condensate system is a high pressure application, steam boiler feed pumps are generally high head, low flow pumps, making multistage pumps a common choice.

2. DESIGN

There is no rigorous procedure to be followed in designing a pump. Lot of approaches have been developed and, although each has a slightly different method of calculation, the broad underlying principles of all are similar. The velocity limitations and proportions are also there to which it requires to adhere; but these may be exceeded in certain instances to meet competition with regard to cost or performance. The usual design is based upon a certain desired head and capacity at which the pump is operated most of time [4]. In design of centrifugal pump, the parts to be designed are: shaft, impeller, vane, casing, and selection of bearing. To design these parts different methodologies can be obtained through literature survey. From the given conditions, the specific speed is obtained [5].

According to required head, the flow rate and from specific speed, pump of double volute, double suction and single stage type is selected. The minimum shaft diameter can be obtained by using maximum shear stress theory. Impeller and vane are designed according to methodology provided by Church [6]. To design the vane empirical relations are used. API standard [7] is used to design the volute and for bearing selection. There are different methods for volute design, but "throat area from graph of ratio of throat velocity to impeller peripheral speed vs. specific speed" method is used to design a volute. The conversion of KE to PE is very important in pump and that can be achieved with the fine shape of volute. According to selection criterions stated in API standard [7], selection of bearing has been done.

Specifications of feed pump are cited in table I,

Table I. Specifications of Feed Pump

Specification	Value
Head, H	470 m
Flow Rate, Q	2000 m^3/hr
Speed, N	4200 rpm
Shaft Power	2.87 MW
Temperature	120 °C to 140 °C
Pressure	6 bar
Density	1000 kg/m^3

3. DESCRIPTION OF THE EQUIPMENT

BOILER FEED PUMP 4B Boiler Feed Pump (BFP) is used to pump the feed water (chemically treated water) in to the boiler. The FK6D30 type BFP consists of FAiB56 Booster Pump (BP) directly driven from one end of the shaft of an electric motor. BFP is driven from the opposite end of Motor shaft through a spacer type flexible coupling. The BP is a single stage, horizontal, axial split casing type, having the suction and discharge branches on the casing bottom half, thus allowing the pump internals to be removed without disturbing the suction and discharge pipe work or the alignment between the pump and the driving motor.

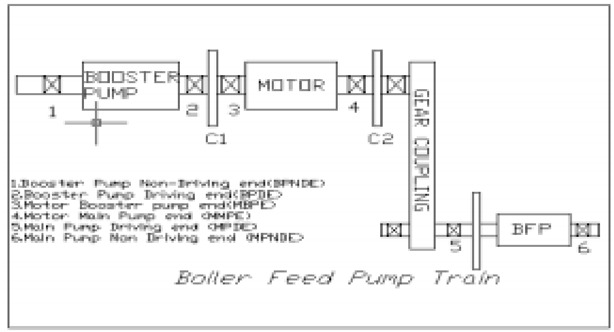


Fig: feed pump train

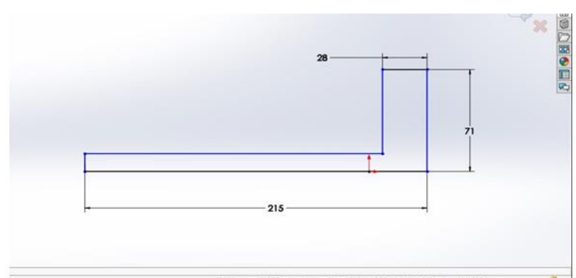
The rotating assembly consists of the shaft, Impeller, nuts, keys, seal sleeves, thrust collar, the rotating parts of the mechanical seals, pump coupling. The rotating assembly is supported at each end of the shaft by a white metal lined journal bearing. The residual axial thrust is taken up by a tilting double thrust bearing mounted at the non-drive end of the pump. The present work deals with the BP which is connected to the motor directly. The pump motor unit is supported by four Bearings. The line diagram of the entire unit is shown in fig

4. INTRODUCTION TO SOLIDWORKS

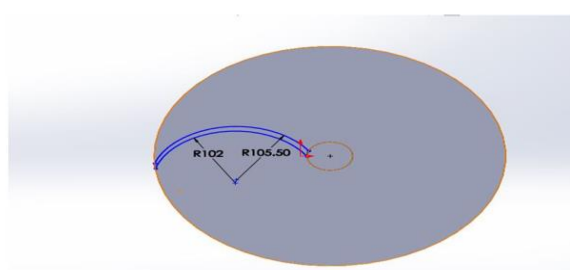
Solid works mechanical design automation software is a feature-based, parametric solid modelling design tool which advantage of the easy to learn windows TM graphical user interface. We can create fully associate 3-D solid models with or without while utilizing automatic or user defined relations to capture design intent etc.

Modeling of centrifugal pump

Draw the sketch as follow and revolve

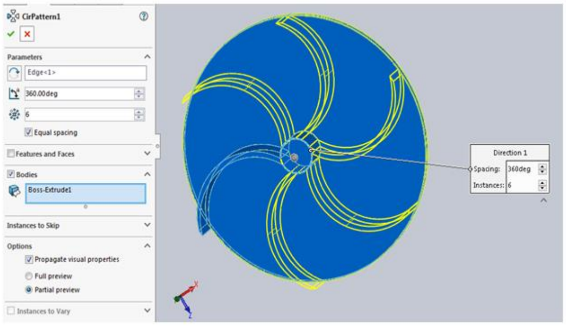


Draw sketch as follow for blade and extrude

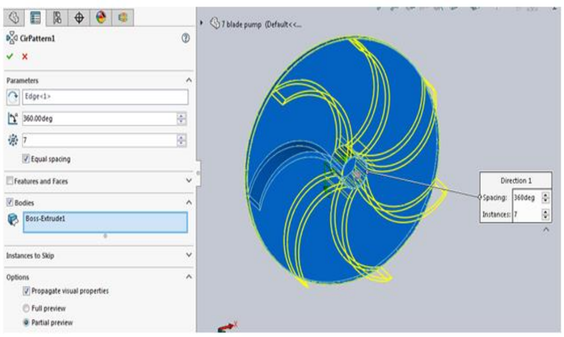


Circular pattern for blades

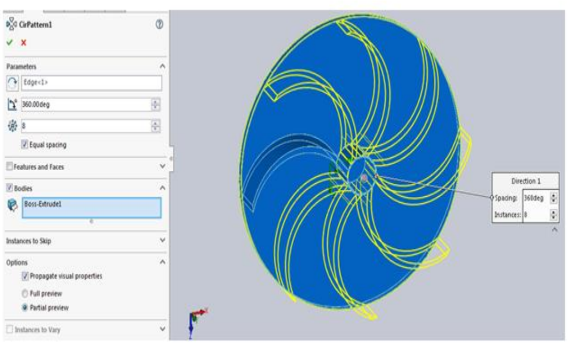
For 6 blade impeller , select 6 nos of pattern.



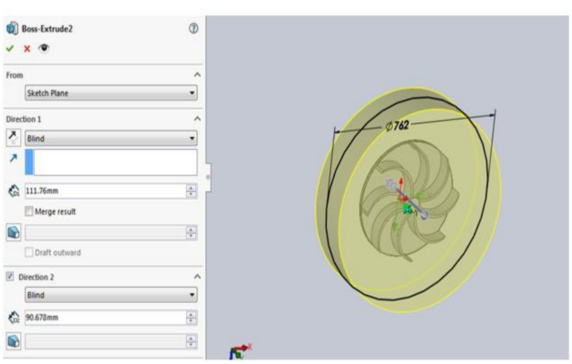
For 7 blade impeller, select 7 nos of pattern.

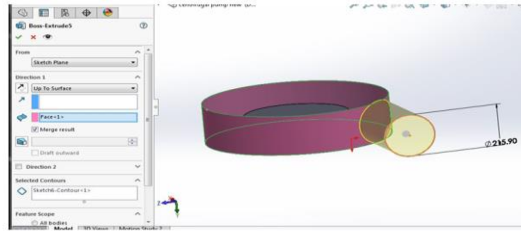


For 8 blade impeller , select 8 nos of pattern.

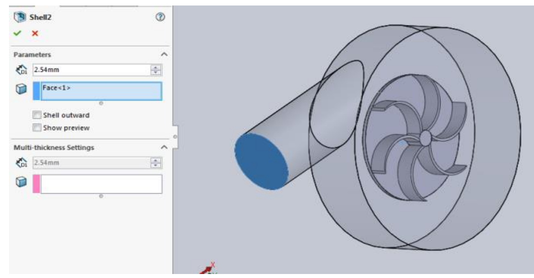


Sketch and Extrude for casing

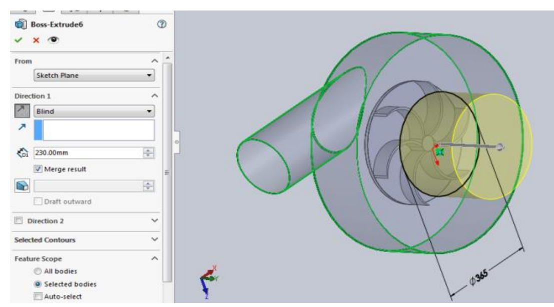




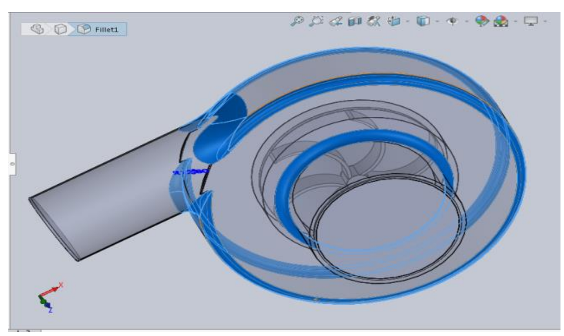
Shell the faces and make it hollow part from inside



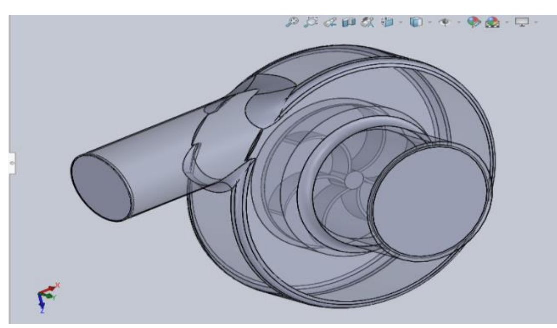
Extrude the part accordingly



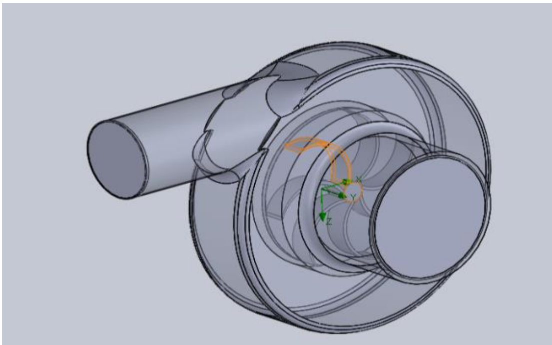
Fillet the edge



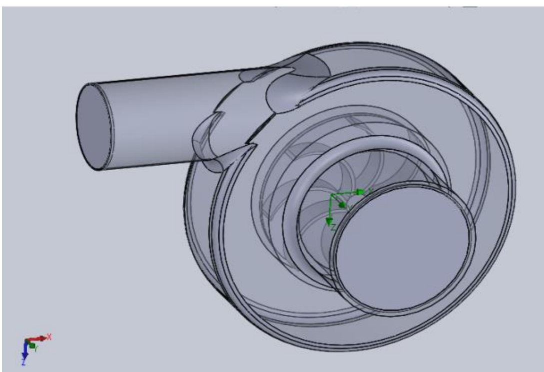
Isometric view of centrifugal pump



6 nos impeller blades



7 nos impeller blades



8 nos impeller blades

TO SOLIDWORKS SIMULATION

SolidWorks Simulation is a design analysis system fully integrated with SolidWorks. SolidWorks Simulation provides simulation solutions for linear and nonlinear static, frequency, buckling, thermal, fatigue, pressure vessel, drop test, linear and nonlinear dynamic, and optimization analyses.

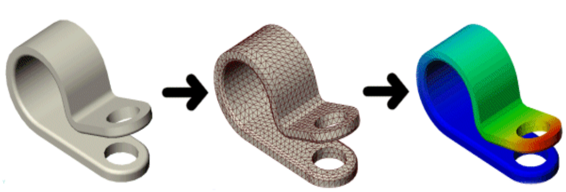


Fig simulation example

FINITE ELEMENT METHODS

The software uses the Finite Element Method (FEM). FEM is a numerical technique for analyzing engineering designs. FEM is accepted as the standard analysis method due to its generality and suitability for computer implementation. FEM divides the model into many small pieces of simple shapes called elements effectively replacing a complex problem by many simple problems that need to be solved simultaneously.

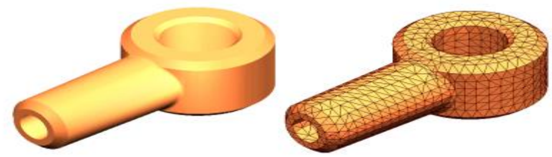


Fig Model subdivided into elements

Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) includes fluid flow, heat transfer, mass transfer and related phenomena by solving the mathematical equations which govern these processes using a numerical process.

The result of CFD analyses is relevant engineering data used in:

(i) Conceptual studies of new designs.

(ii) Detailed product development.

(iii) Troubleshooting.

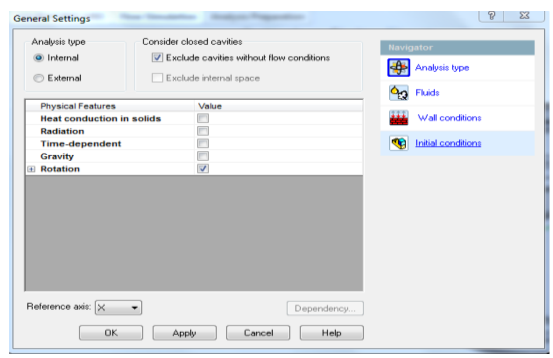
(iv) Redesign.

CFD analysis complements testing and experimentation. Reduces the total effort required in the laboratory.

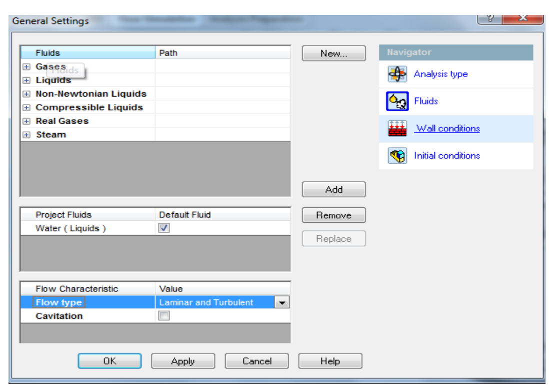
CFD ANALYSIS

6 Numbers impeller blade

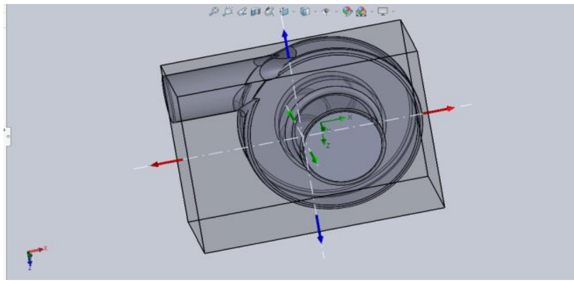
General setting for internal type of flow,with rotation.



Select water as fluid and and assign flow type



Computational domain

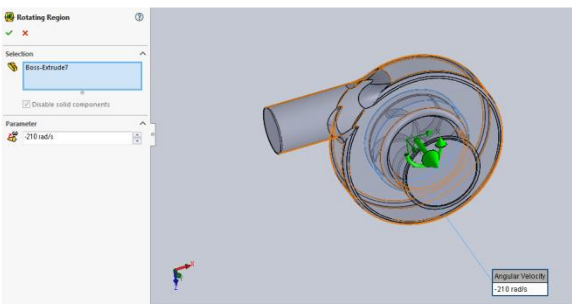


Rotation of impeller

Convert Rpm to Rad/sec –

2000rpm is equal to 210 rad/sec approx.

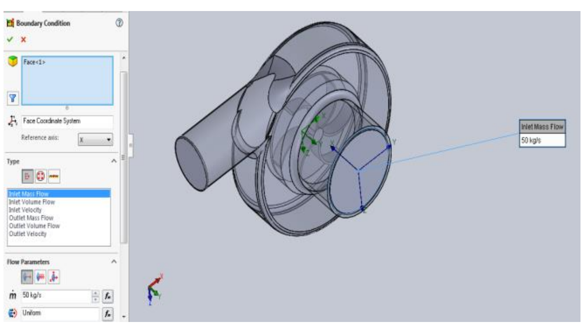
Negative sign for change of direction



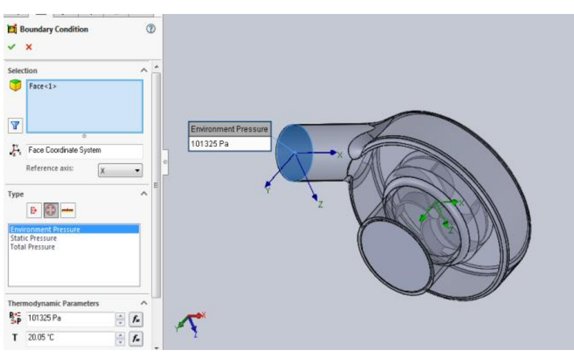
Boundary condition

At Inlet

Mass flow rate as 50Kg/sec , temp 70 deg C

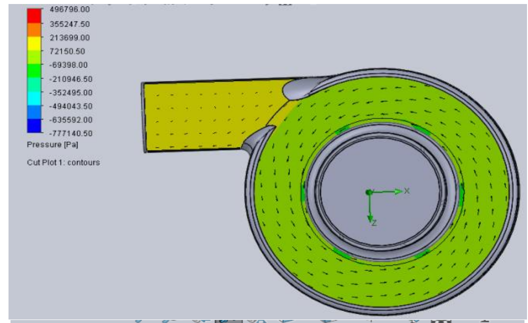


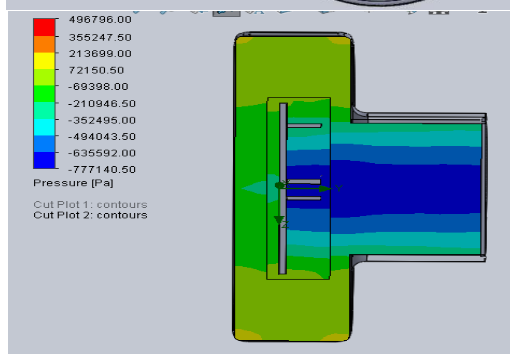
At outlet



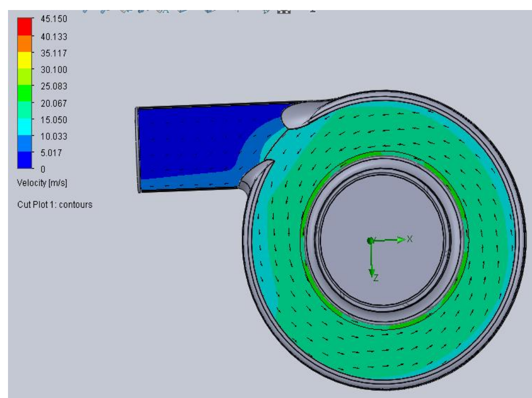
5. RESULTS

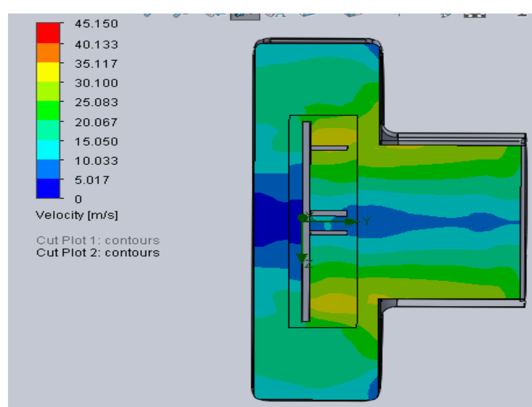
Pressure





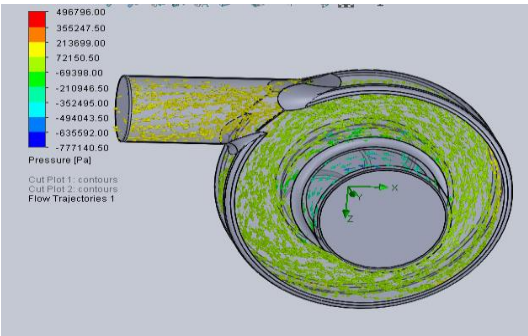
Velocity



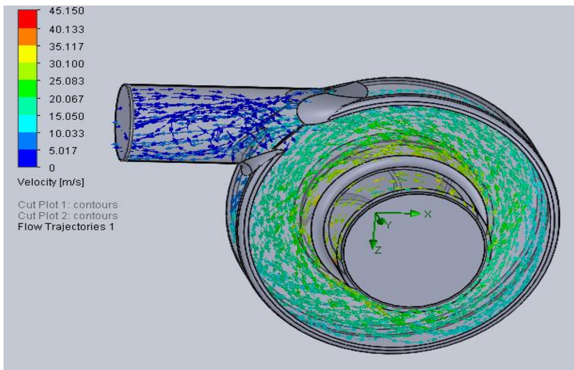


Trajectories

Pressure

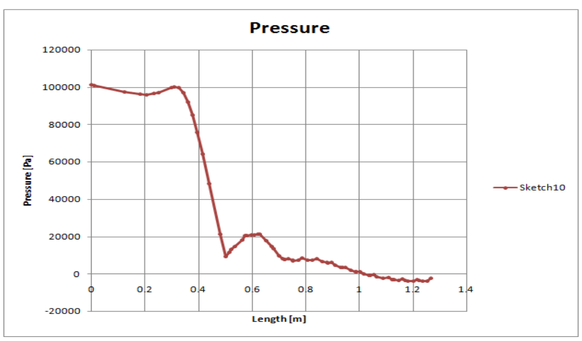


Velocity

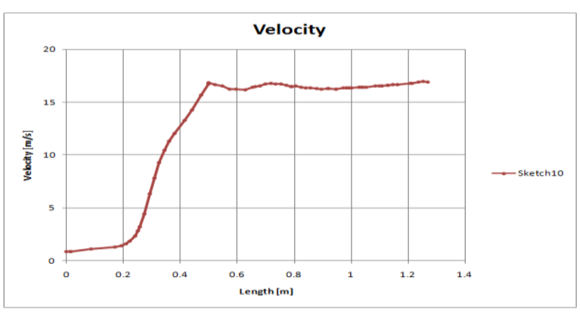


Graph

Pressure



Velocity

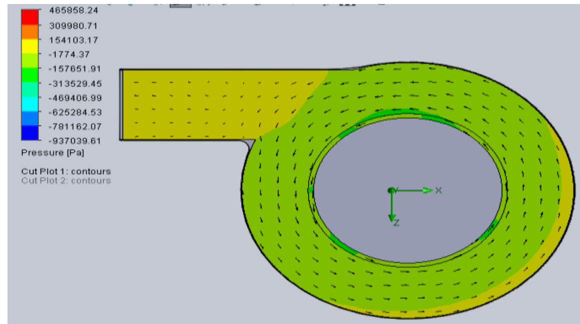


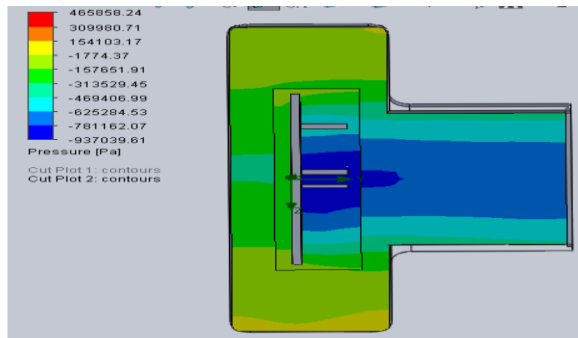
7 Numbers Impeller Blades:

Same boundary conditions are applied as 6 no blade impeller

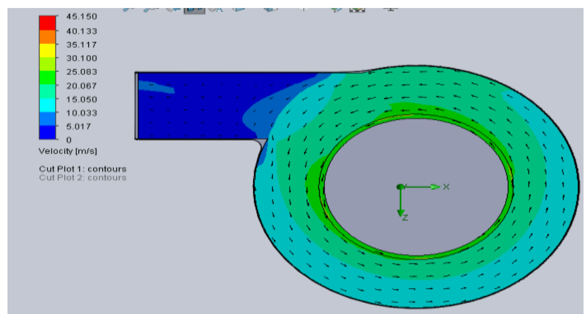
Results

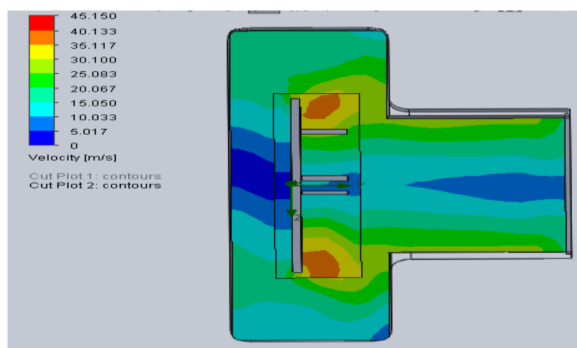
Pressure





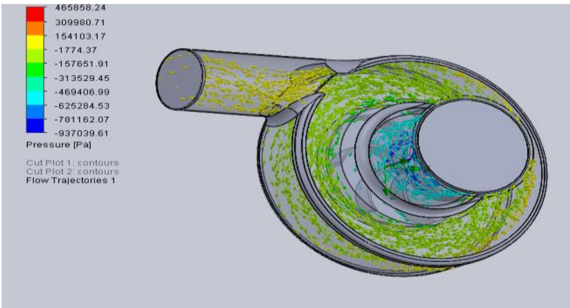
Velocity



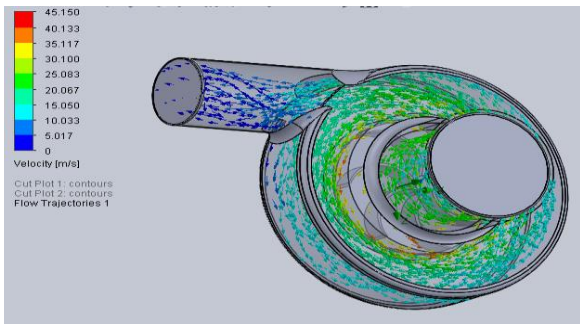


Trajectories

Pressure

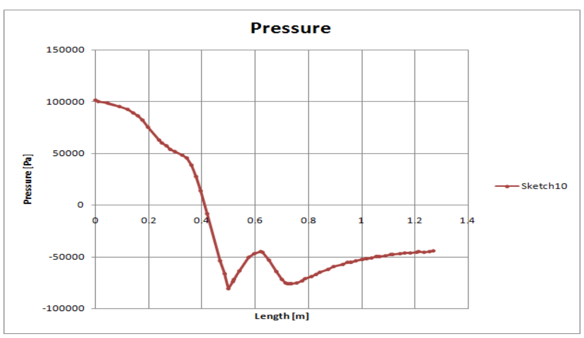


Velocity

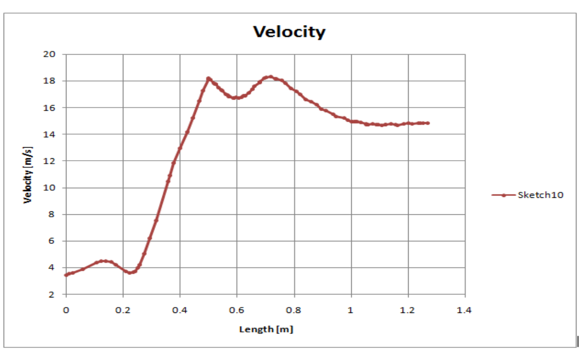


Graph

Pressure



Velocity

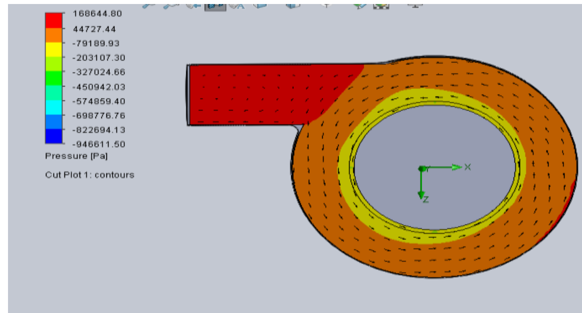


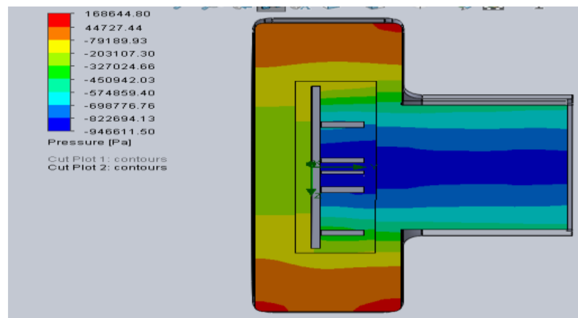
8 Numbers Impeller Blades

Same boundary conditions are applied as 6 and 7 no's blade impeller

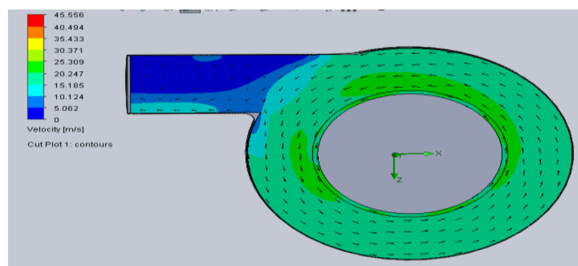
Results

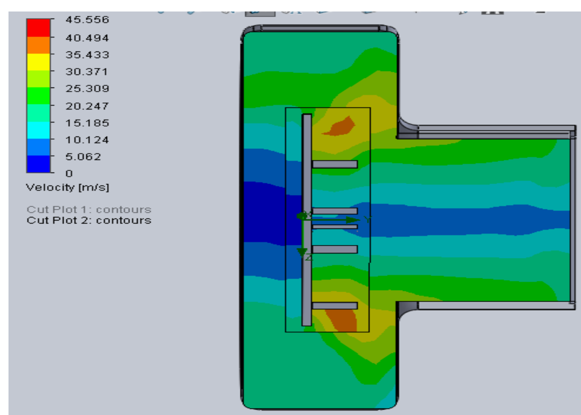
Pressure





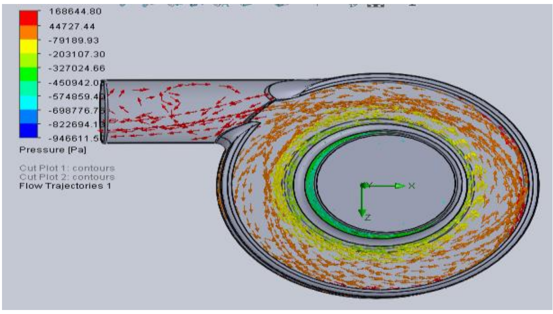
Velocity



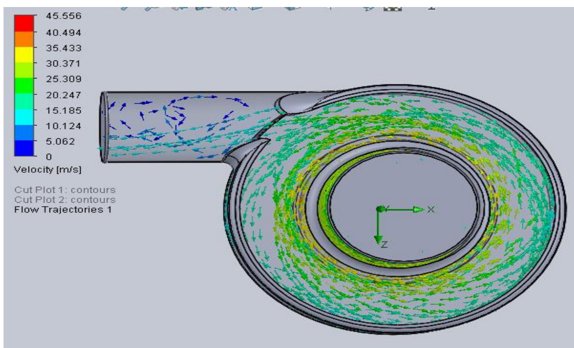


Trajectories

Pressure

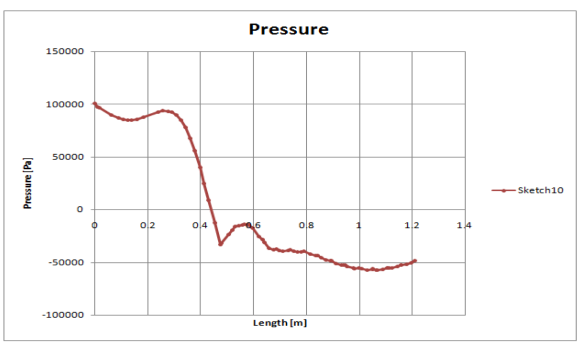


Velocity



Graph

Pressure



Velocity

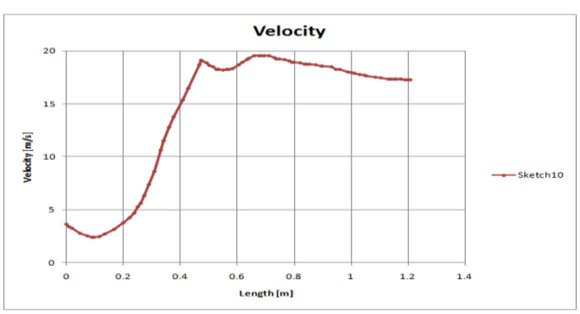


Table .Result

Flow characteristic	6 No's	7 No's	8 No's
Pressure (pa)	496796.00	465858.24	168644.80
Velocity (m/s)	45.150	45.150	45.556

6. CONCLUSION

- Design and CFD analysis is done on boiler feed pump.
- Brief study about boiler feed pump its application, classification is studies in this project.
- Three different models of boiler feed pump with 7, 8, 9 no's of impeller blades is modelled in solidworks 2016 software.
- Computational fluid dynamic analysis is performed in Solidworks Flow simulation module on three different geometry with same boundary conditions
- Flow characteristics like pressure and velocity are noted and tabulated.
- Flow characteristic pressure and velocity are shown in counters and trajectories.
- From result table we can conclude that as the numbers of blades of impller are increasing pressure inside the pump is decreasing.
- And as the numbers of blades of impeller are increasing velocity is slightly increasing as a result pressure decreases.
- Hence the impeller with 6 no's blades has high pressure and nearly same velocity of water than 7 and 8 no's of blade inside pump.
- To force water into boiler, the pump must generate sufficient pressure to overcome steam pressure developed by boiler.
- According flow trajectories of 7, and 8 no's blade which has low pressure has back flow of water at outlet into pump because of steam pressure of boiler.
- Hence we can conclude that 6 no's blade impeller boiler feed pump which create more pressure is better than 7 and 8 no's impeller blade boiler feed pump.

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