

Impingement wastage experiments with 9Cr 1Mo steel

S. Kishore^{a,*}, François Beauchamp^b, Alexandre Allou^b, A. Ashok Kumar^a,
S. Chandramouli^a, K.K. Rajan^a

^a IGCAR, India

^b CEA, France

HIGHLIGHTS

- Sodium heated steam generators are crucial components of fast breeder reactors.
- A leak in steam generator tube will cause sodium water reaction that damages the tubes.
- A collaborative study by CEA and IGCAR was conducted to quantify the extent of damage on 9Cr 1Mo tube due to a steam/water leak.
- It was compared against the predictions of PROPANA code.

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ABSTRACT

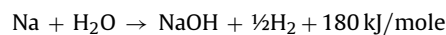
Steam Generator (SG) is one of the vital components of sodium cooled fast reactor (SFR). The main safety concern with SG is a probable sodium–water reaction. In case, one of its water/steam carrying tubes leaks, water/steam gets into contact with sodium causing sodium–water reaction, which is highly exothermic and producing corrosive NaOH and hydrogen. The ejecting reaction products at high temperature, impinges upon adjacent tubes by a process called impingement wastage. It could damage one of the neighboring tubes in a short time, if the detection and protection systems are failing. IGCAR and CEA carried out a collaborative study on impingement wastage of 9Cr 1Mo steel, which is one of the candidate materials for SFR SG tubes. The studies comprise of experimental works at IGCAR and simulation works with PROPANA code at CEA. This paper brings out the data and experience gained through this cooperative work.

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1. Introduction

Liquid sodium is the unanimously chosen coolant for fast reactors due to its low neutron moderating and high heat transfer properties. Its low vapor pressure and high boiling point facilitate design of a low pressure reactor system, working at high temperature. Sodium heated steam generator (SG) is one of the vital components of Sodium cooled Fast Reactor (SFR). SG is typically a once through, shell and tube heat exchanger, where hot sodium exchanges heat with water to generate required quality steam for the turbine. Sodium, flowing in the shell side at a lower pressure, is separated from high pressure water/steam, flowing in the tube side (at about 17.2 MPa) by a single wall tube. A defect on the tube

causes leakage of water/steam into sodium resulting in sodium–water reaction in the shell side. The reaction is highly exothermic in nature, accompanied by liberation of hydrogen and corrosive NaOH.



The very high reactivity of sodium with water stipulates high integrity of SG. The effect of steam generator leak depends largely on the magnitude of the leak rate (Hori, 1980; Saez et al., 2013). The main effects of medium (50 g/s–1 kg/s) and large leaks (>1 kg/s) are hydrogen pressurization and heat generation. The main effect of a small leak (<50 g/s), is ‘damage of a single adjacent tube’, called impingement wastage or adjacent tube wastage. It can puncture the adjacent tube in a short time, causing a secondary leak, which will be much higher than the original one. Leaks less than 100 mg/s are called micro leaks which would cause the leaking tube itself to get damaged, called self wastage. For SFR SG safety studies, the characterization of the wastage resistance of the SG tubes is needed to assess the performance of the detection systems for triggering

* Correspondence to: Scientific Officer-F, Fast Reactor Technology Group, Steam generator Test Facility, Indira Gandhi Center for Atomic Research, Kalpakkam, Tamilnadu 603102 Tel.: +91 044 27480500x21152.

E-mail address: skishore@igcar.gov.in (S. Kishore).

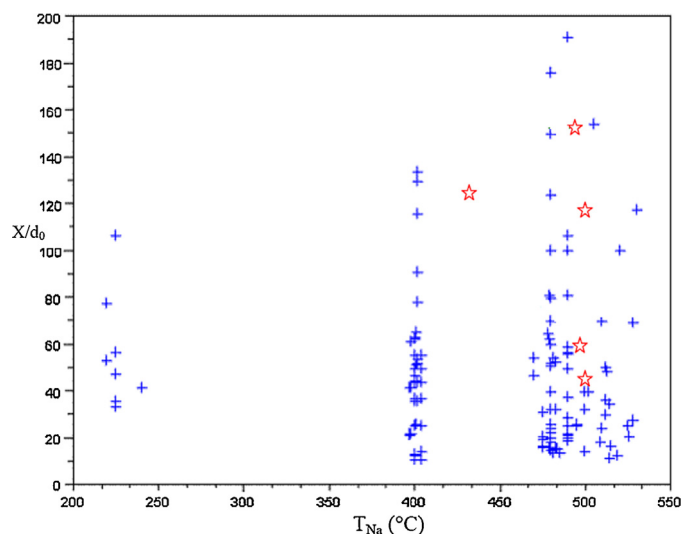


Fig. 1. Distribution of wastage data for Mod 9Cr 1Mo steel versus the sodium temperature and the dimensionless distance between the target (X) and the injector diameter (d_0).

the safety actions before the appearance of a secondary leak. Moreover, it is well known that the wastage rate is strongly correlated with the type of material of the SG tubes and its intrinsic behavior. Usually, during SG material selection, the following points are considered: compatibility of material with sodium, aqueous and caustic environment, thermal conductivity, wastage resistance and mechanical strength. Ferritic steels such as 2-1/4Cr 1Mo steel were widely used for SGs of earlier SFRs. Presently, 9Cr 1Mo steel is a more preferred material owing to its superior high temperature mechanical properties, better resistance towards caustic and chloride stress corrosion cracking, resistance against decarburization and wastage resistance. Extensive wastage data on 9Cr 1Mo material are not available. In this context, IGCAR and CEA initiated a collaborative study. Fig. 1 gives the available wastage data base for this material. It could be found that wastage data in lower temperature region (below 400 °C), and the intermediate temperature between 400–480 °C are very few. Around 500 °C, it shows notable scattering also. The collaborative study comprised of sodium–water reaction experiments carried out at IGCAR and analytical works with PROPANA code at CEA. Earlier studies carried out in IGCAR (shown in Fig. 1 in red mark) on impingement wastage were mostly on the higher temperature (Kishore et al., 2012).

The cold end of SG, where sodium leaves out would be at around 350 °C and the hot end where sodium enters would be at around 525 °C. The experiments were organized in such a way to simulate leaks at different temperature zones of SG. The wastage rate would be highest in the high temperature region. Hence experiments at high temperature would be more conservative. Out of ten planned experiments, two were in low temperature zone (340–350 °C), two in intermediate 420 °C, and six in high temperature above 475 °C. Each of the experiment requires about 1½ months time, including the times for preparation, sodium purification and post-test measurements. Ten experiments could be realistically completed within the time frame of IGCAR–CEA mutual agreement.

2. Impingement wastage

Impingement wastage phenomenon, due to a sodium–water reaction is schematically shown in Fig. 2 (Roger et al., 2014). Three zones can be seen in the under-expanded jet.

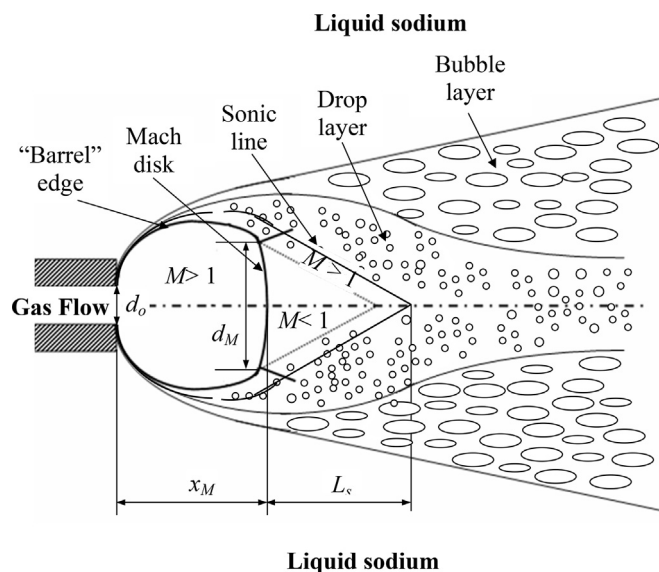


Fig. 2. Underexpanded gas jet into liquid (Roger et al., 2014)

For the first one a shock barrel structure occurs in the vicinity of the leak. In this zone the central part is made of high velocity steam. At the interface the droplets of sodium are snatched and start to move toward the gaseous core.

The second one is located around the Mach disk (see Fig. 2). Droplets and shock wave interact. Lambda shock can be seen around the Mach disk next to the interface of sodium. In this zone some Taylor–Görtler instabilities start to grow. They find its origin with the roughness at the nozzle.

The third zone is downstream of the sonic line. At this location next to the axis of the jet a droplet layer is mixed with a surrounding layer of bubbles of gas into sodium. The Taylor–Görtler stream wise pair of contra-rotative vortices starts to merge and grow. These structures strengthen the mixing between the sodium, the water and their reaction products. In this zone the local temperature becomes high and can reach 1550 K (Roger et al., 2014).

Farther downstream water has completely react with the sodium, the reaction products of the SWR begin to slow down then the Froude number (ratio of inertial and gravitational forces) rises and the flow is mostly vertical and bubbles dominated. The temperature of the jet is cooled down too.

When corrosive reaction products impinge the adjacent tube, corrosion combined with erosion occurs, ultimately causing the adjacent tube to puncture. The main parameters affecting adjacent tube wastage are: steam leak rate, sodium temperature, tube material, distance between leaking tube to target tube, and sodium velocity. Wastage characteristics are important design data required for leak detector developments and for fixing the thresholds for SG safety logics.

Earlier, many countries such as USA, France, USSR, UK, Japan etc had developed test facilities to conduct sodium water reaction experiments to gain wastage data on different materials such as 2.25 Cr 1Mo steel, 800 incoloy, and type 300-stainless steel, etc. Specimens were tested and wastage correlations could be established. (Chamberlain et al., 1970; Hori, 1980; Dumm, 1974; Desmas and Lemoine, 1984).

3. Sodium Water Reaction Test Facility (SOWART)

Impingement wastage experiments were performed in Sodium Water Reaction Test Facility (SOWART) in IGCAR (Fig. 3). It is designed to handle sodium at a maximum temperature of 530 °C.

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